

# **Final Report**

## **Shearography NDE of NASA COPV**

**Tests Performed at NASA  
White Sands Test Facility, NM  
Sept. 12-16, 2006**

**Prepared By  
John W. Newman  
October 25, 2006**



***Laser Technology Inc.***  
Aerospace Inspection Systems

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# ***Final Report - Shearography NDE of NASA COPV***

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# ***Final Report - Shearography NDE of NASA COPV***

## **Section 1.0**

### **Summary**

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- 1. 21 Composite Over-wrapped Pressure Vessels (COPV) consisting of Kevlar Space Shuttle Fleet Leaders and Graphite COPV were inspected at NASA WSTF, NM from Sept. 12 through Sept 16.**
- 2. The inspection technique was Pressurization Shearography, tests designed to image composite material damage, degradation or design flaws leading to stress concentrations in the axial or hoop strain load path.**
- 3. The defect types detected consisted of the following:**
  - Intentional impact damage with known energy.**
  - Un-intentional impact damage.**
  - Manufacturing defects.**
- 4. COPV design features leading to strain concentrations detected include:**
  - Strain concentrations at bosses due to fiber closure pattern.**
  - Strain concentrations in body of COPV due to fiber wrap pattern.**
  - Strain concentrations at equator due to liner weld/fiber lay-up.**



## **Summary, Cont'd.**

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5. Shearography compliments other NDE techniques, such as Visual Inspection.
  - Of 51 shearography indications detected on Kevlar COPV and Graphite Cylinder COPV, 9 were not detected visually. (See 7.0 Defect Guide)
  - The extent of subsurface composite matrix damage and delamination due impact, can be measured with Pressurization Shearography.
6. Kevlar COPV results are presented in Section 9.0, herein.  
Graphite COPV results are presented in Section 10.0, herein.

**John Newman  
Laser Technology Inc.  
October 25, 2006**





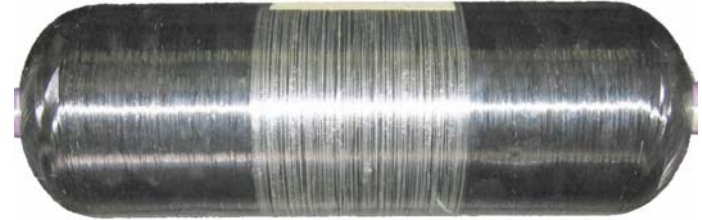
# Shearography NDE of Space Shuttle COPV

## COPV Types Inspected

**10 Inch Graphite Sphere**



**6 x 22 Graphite COPV**



**26 Inch Diam. Kevlar Fleet Leader**



**10 Inch Kevlar Fleet Leader**



## Section 2.0

# Shearography NDE of NASA COPV Significance of Test and Results

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1. Shearography inspection of COPV is a new, promising tool for the evaluation of manufacturing defects, damage from impact or degradation from high temperature, chemical or radiation exposure. Although used by the author on Delta IV COPV and on other programs, this series of tests at WSTF is the first application of Digital Phase Shearography for NASA COPV.
2. Shearography COPV NDE has the capability to image and measure sub-surface, non-visible matrix damage, quickly and with excellent repeatability.
3. These tests were designed to detect local changes in surface axial and hoop strain caused by damage to the composite matrix or manufacturing defects. Lessons learned during these tests will improve technique and results in the future.
4. While the damage detection capability has been clearly demonstrated, the specific effect of such damage on COPV creep rupture characteristics, reduction in burst strength and life time performance has not been established.



## Section 3.0

# Shearography NDE Team Performing Tests NASA White Sands Test Facility, NM Sept. 12-16, 2006



Paul Ogletree	USA KSC
Dr. Brad Regez	USA KSC
Jim Landry	USA KSC
Leo Going	USA KSC
John Newman	Laser Technology Inc.
Ken Tauer	USA KSC



## Section 4.0

# Background On Shearography NDE



## Equipment used for these tests was the LTI-5100 All Mode, Digital Shearography System



### Features:

- Z Axis deformation to 2 nm.
- Quantitative displacement measurement capability.
- Damage/Defect size area measurement.
- Remote control of all camera parameters allows testing in hazardous environments.
- Eye safe Class IIIa Laser System.
- Training to ASNT TC-1A Level II and III.

# Flat Circular Plate Deformation With Center, Single Point Load *Phase Maps for: $\frac{\partial W}{\partial x}$ and $\frac{\partial W}{\partial y}$*

120 mm. Diam.  
5mm. Thick  
Flat Plate

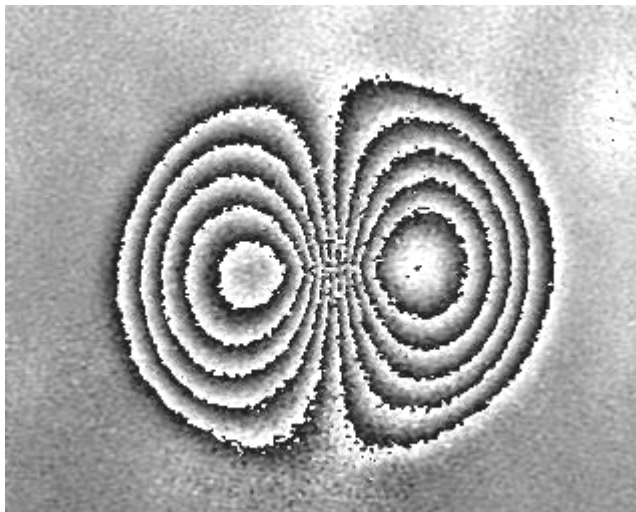


Z Axis Displacement  
change  $W$ , measured  
mechanically as  $7\mu$



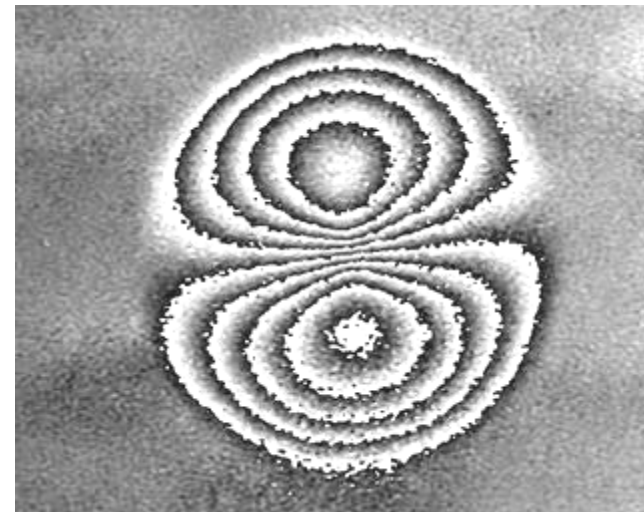
Shearography  
Camera

$$\frac{\partial W}{\partial x}$$



Horizontal 0° Shear Vector  
**Laser Technology Inc.**

$$\frac{\partial W}{\partial y}$$



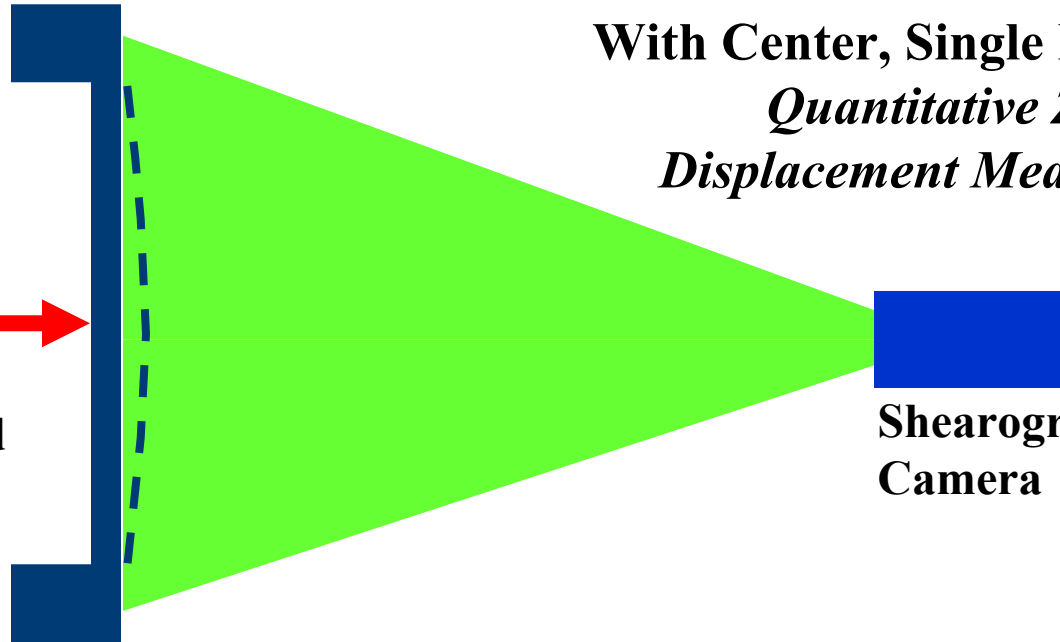
Vertical 90° Shear Vector



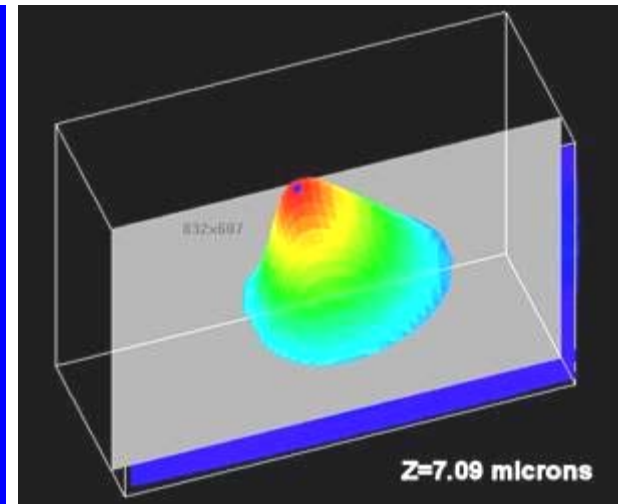
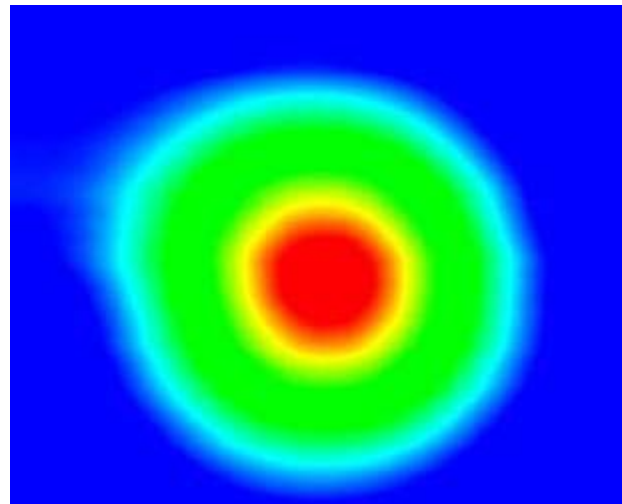
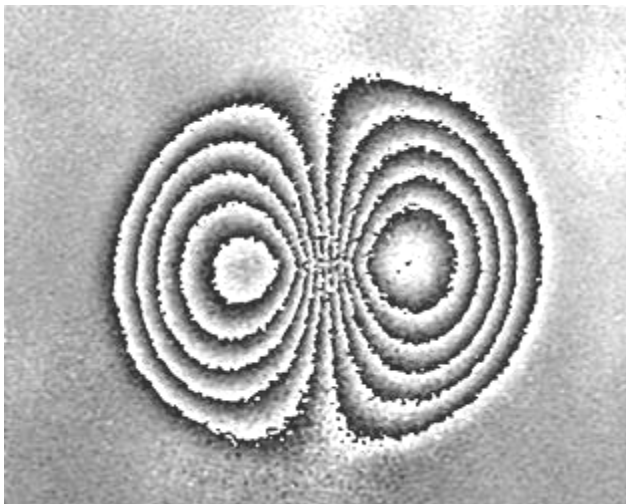
# Flat Circular Plate Deformation With Center, Single Point Load: *Quantitative Z Axis Displacement Measurement*

120 mm. Diam.  
5mm. Thick  
Flat Plate

**Z Axis Displacement  
change W, measured  
mechanically as 7μ**



**Shearography  
Camera**



Phase Map  $\frac{\partial W}{\partial x}$

Integration  $\int \frac{\partial W}{\partial x} dx$

3-D Plot and measurement  
of Z Axis displacement

**Page 11**



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## Section 5.0

# Background On Shearography COPV NDE



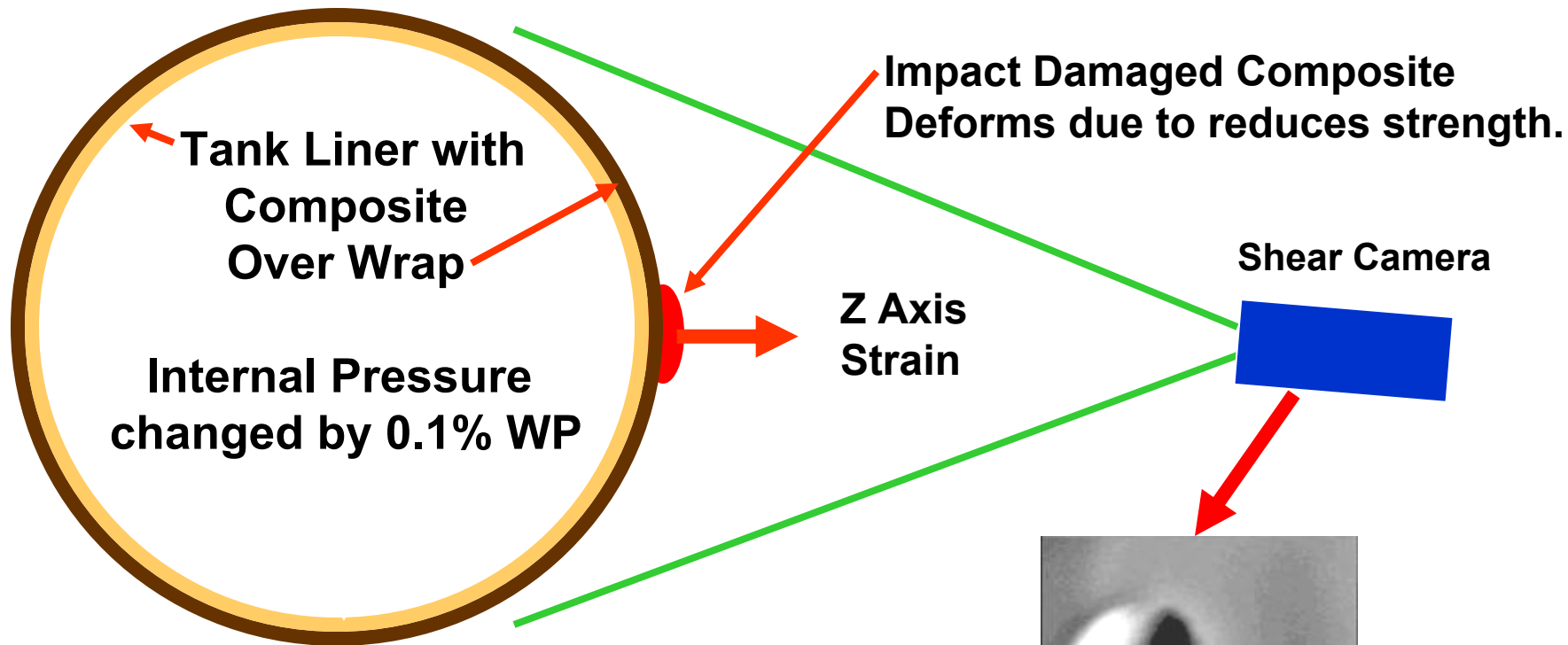


# Shearography NDE of COPV

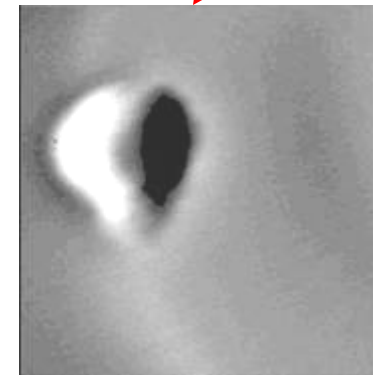
- Full field laser interferometric imaging of COPV composite materials for damage, liner to composite disbonds or design flaws, leading to stress concentrations affecting hoop strain.
- Shearography camera is used with precision control of COPV internal pressure changes.
- Defective composite material dimensions/area are easily measured.



# Pressure Shearography Detection of Defects in COPV



- Raising internal pressure increases hoop and longitudinal strain.
- Z axis component of strain concentrations caused by anomalies are detected by the shearography camera.
- As pressure increases, strain rates at damage areas are greater than good areas.



**Shearography  
Impact Damage  
Indication**

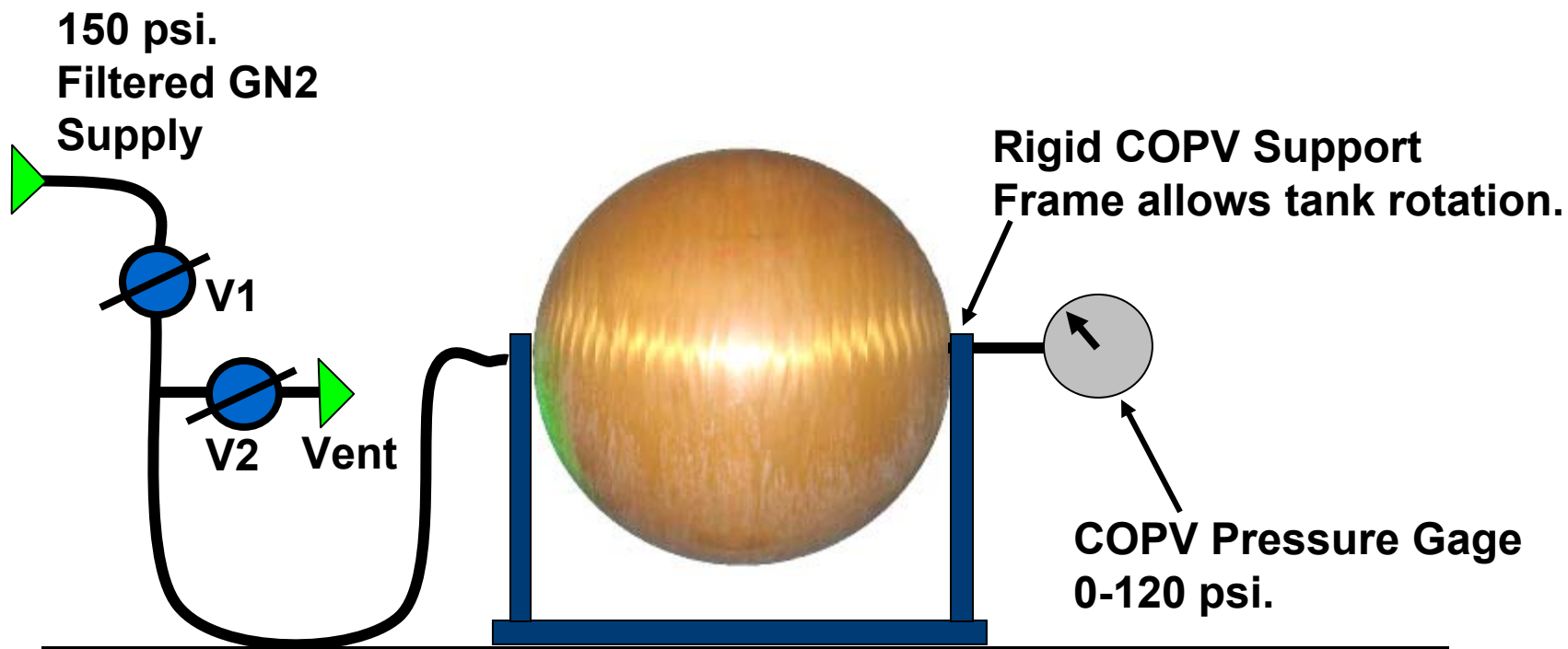
# Shearography COPV Test Procedure

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1. Preparation of COPV Test articles
  - Kevlar COPV were tested without coating
  - Graphite COPV were coated with dye penetrant developer to reduce glare and increase surface reflectivity.
2. Test Article mounted in fixture to provide mechanical stability and allow rotation.
3. Pressure hose fitted with tank gage connected to pressure feed line in blind COPV and to the gage port if present.
4. Pressure in COPV raised to 70 psi. to allow minimum pressure cycle time.
5. An LTI-5100 Digital Shearography Camera System was used with the following parameters:
  - Distance to Part                      34 inches
  - Shear Vector                              0° (axial) @ 0.25 in.
  - Field of view                              (8 in. H x 6.2 in. V) and (11 in. H x 7.3 in. V)



## Shearography Test Set-Up for COPV Testing Pneumatic Operation/Shearography Data Capture



1. V1 opened, pressure raised to 70psi., V1 closed.
2. Shearography reference image captured @70 psi.
3. V1 opened, pressure raised to 90psi., V1 closed.
4. Shearography Stressed image captured @90 psi.
5. Final shearography image computed.

# Shearography Test Set Up at WSTF 9-12-06



**COPV  
Support  
Fixture**

**LTI-5100  
Shearography  
Camera**

**GN2 Valve  
And Pressure  
Gage.**

**LTI-5100 Camera Controls/  
Image Processing Computer**



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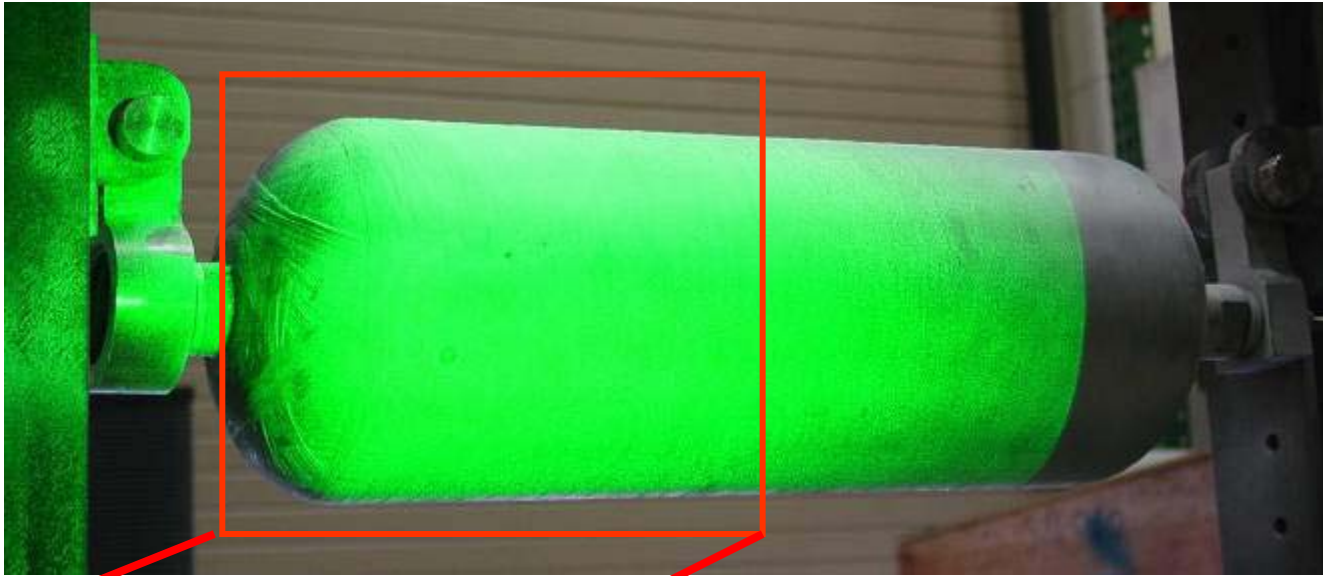
**Page 17**

## Section 6.0

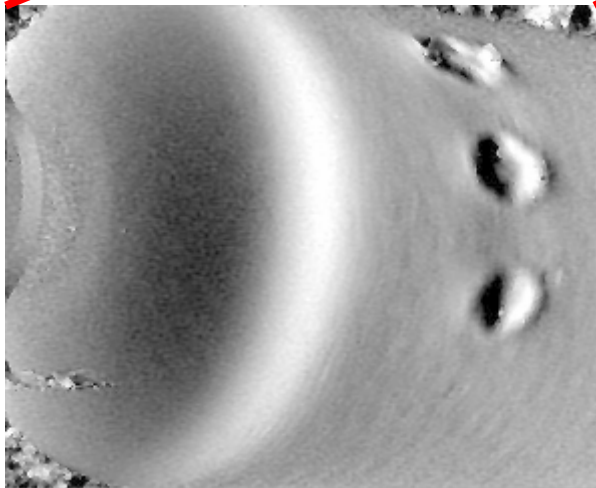
# Interpreting Shearography COPV NDE Results



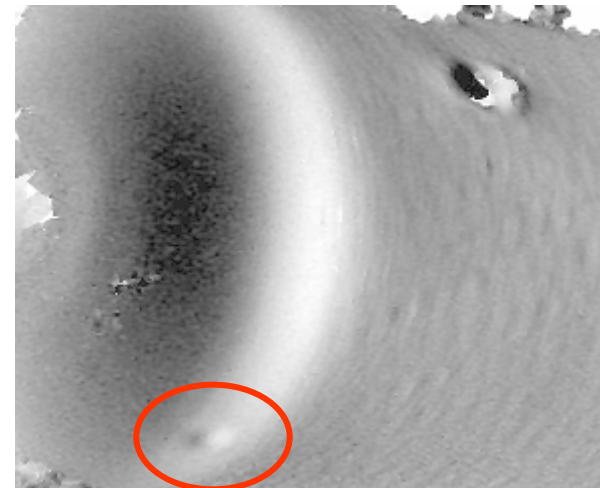
**6 x 22 Inch Graphite COPV Shearography Inspected with 10 psid. Crater like indications are impact induced damage and delamination to the composite.**



**Centered  
At 30°**



**Centered  
At 60°**



**Un-programmed Damage  
Page 19**

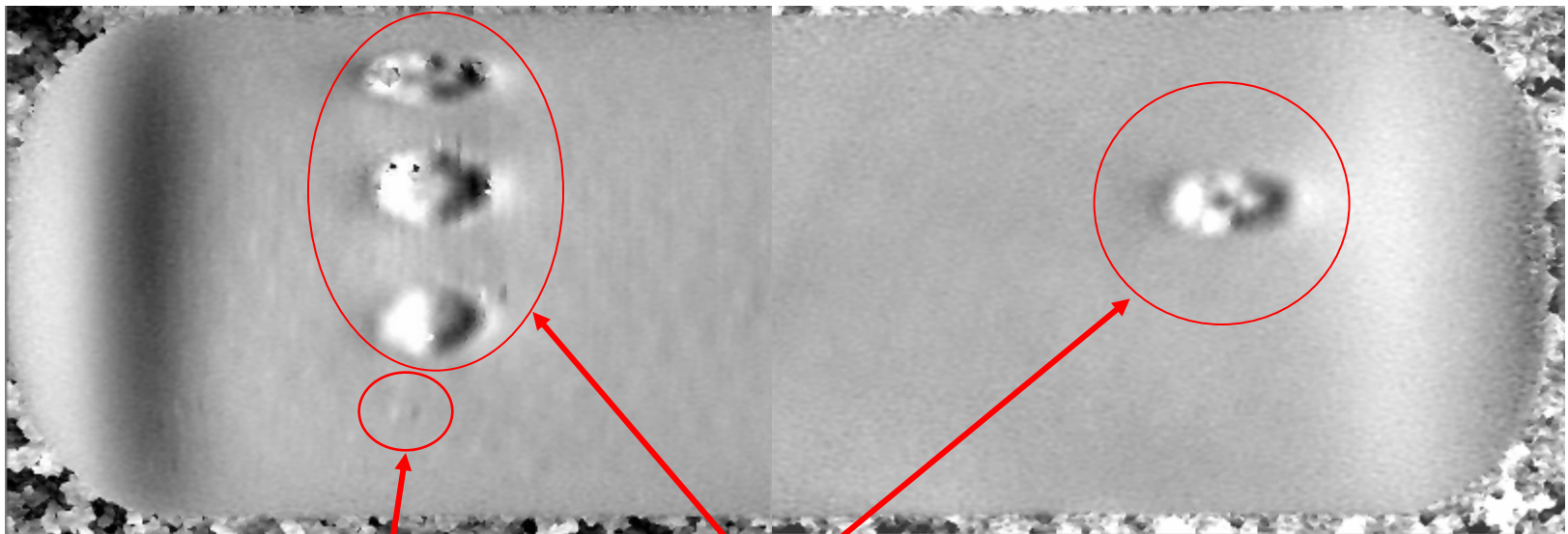


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**6 x 22 Inch Graphite COPV Shearography Inspected with 10 psid.  
Three impact areas are seen and one small un-programmed defect.**



**Un-programmed Damage**

**4 Impact Sites**



## 10 Inch Diam. Carbon Fiber COPV



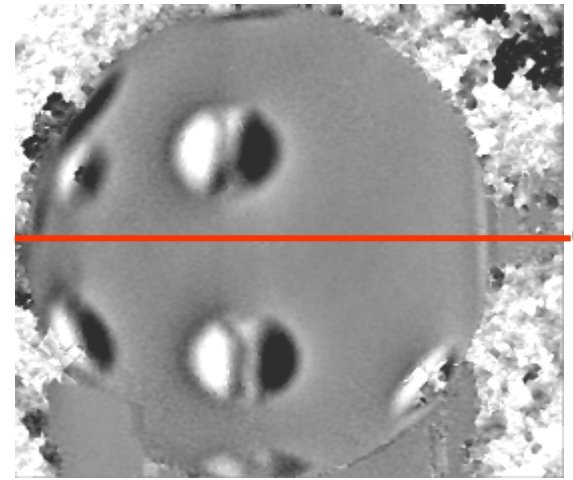
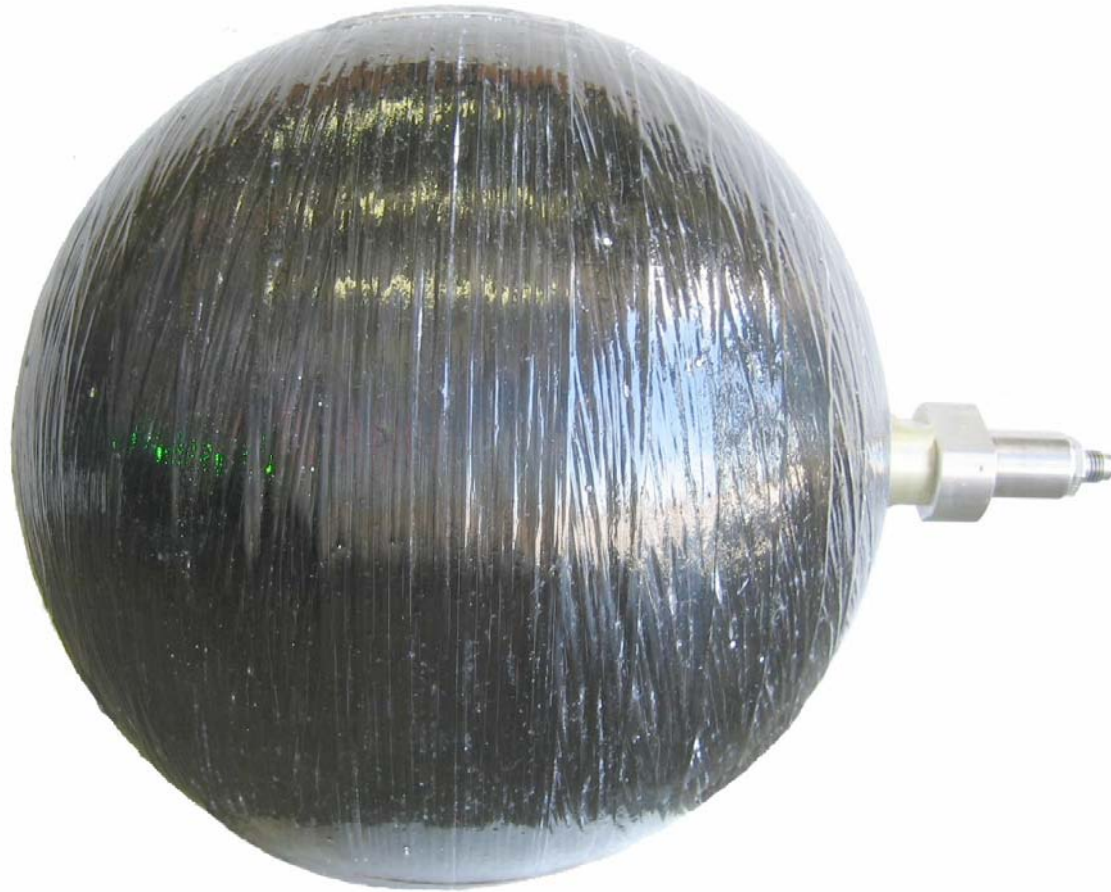
No visible damage except 0.15 inch diameter dimple at impact sites.

## Shearography Test with 1.2 psid

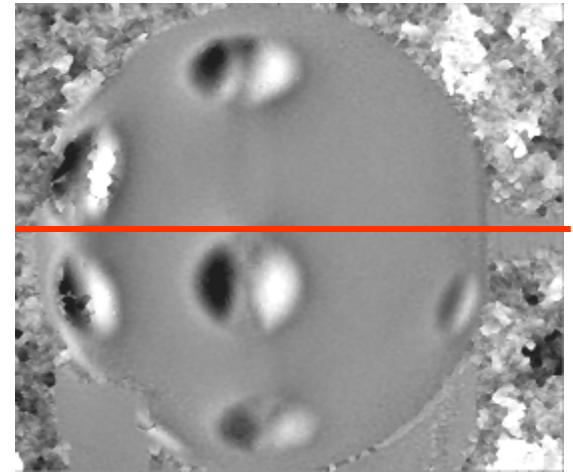


Impact induced delamination .75 to 2.3 inches in diameter.

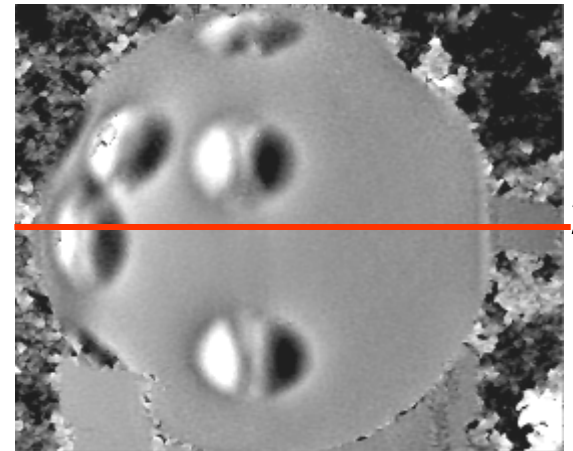
**10 Inch Diam. Carbon Fiber COPV – Typical Images  
Side View Showing Pressure Fitting  
Shearography Test, at right with  
1.2 psid, rotating 120 Degrees per test.**



0°



120°



240°

**No visible damage except 0.15 inch  
diameter dimple at impact sites.**



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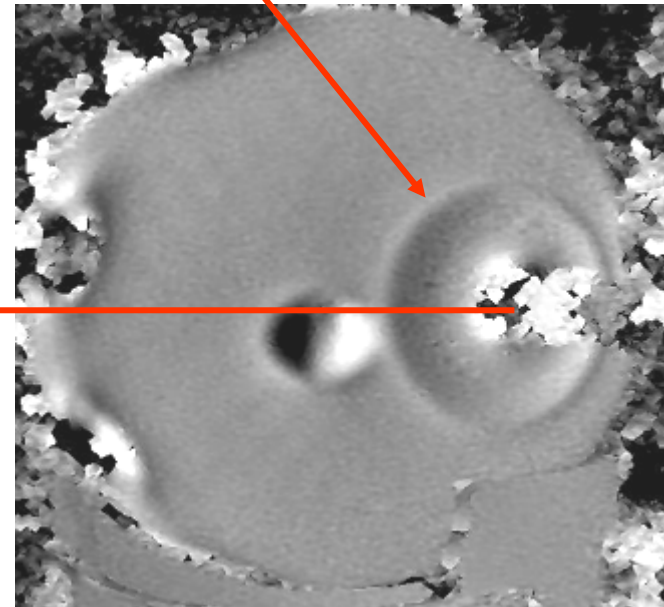
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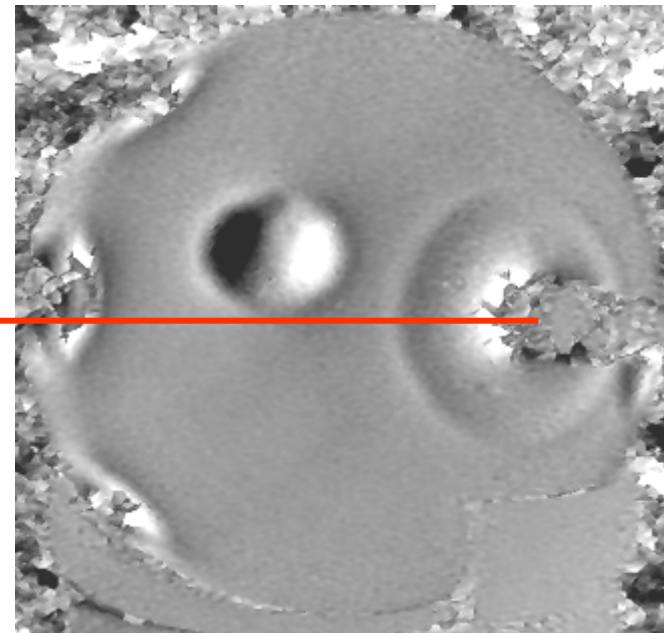
**10 Inch Diam. Carbon Fiber COPV – Typical Images** Stress Concentration Around Boss  
Side View Showing Pressure Fitting  
Shearography Test, at right with  
1.2 psid, rotating 190 Degrees per test.



0°



190°



No visible damage except 0.15 inch diameter dimple at impact sites.



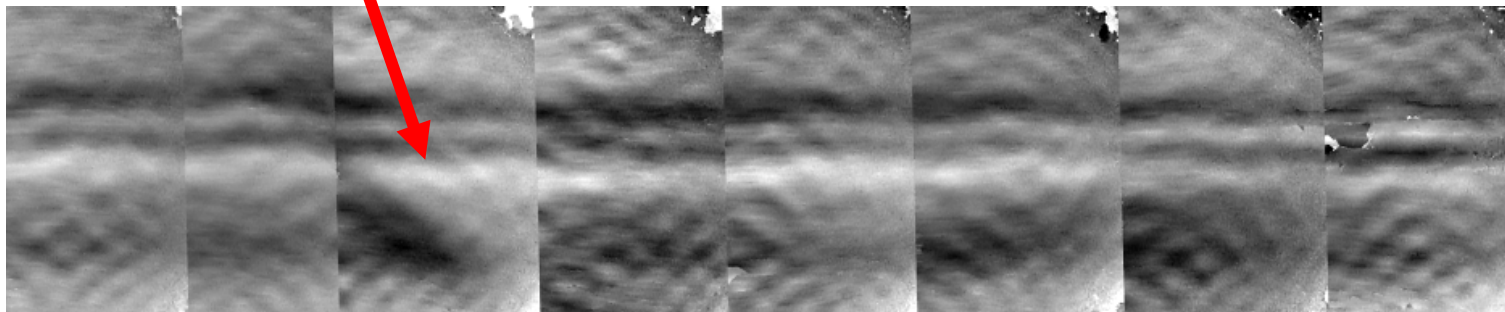
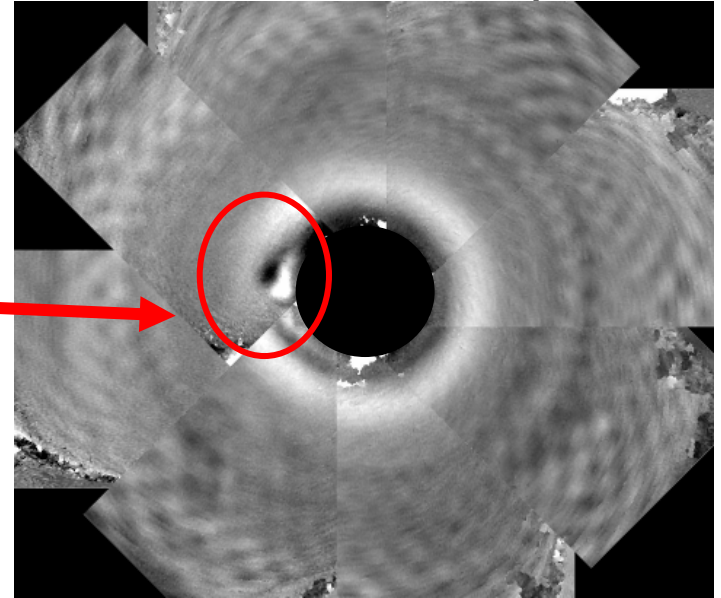
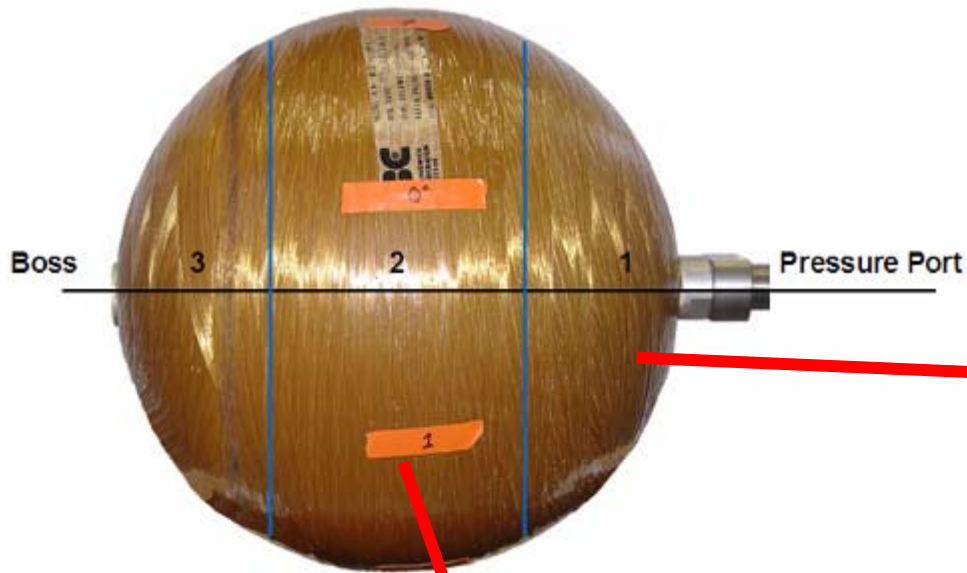
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## 10 ¼ Inch Kevlar COPV – Typical Images

Shearography scan Band 1. The pressure port boss is in the center, a stress riser (circled) due to a defect or fiber closure pattern.



Shearography Scan of Band 2 at the equator showing the Strain concentration over the circumferential liner girth weld.

## **Section 7.0**

# **Shearography COPV NDE Compared to Visual Inspection**

## **Relative Strengths and Weakness**



# **Shearography COPV NDE Compared to Visual Inspection**

---

- 1. Visual Testing of COPV detects:**
  - **Surface fiber breakage.**
  - **Dimpled COPV surface from impact object.**
  - **Changes in surface color, texture, appearance indicative of damage.**
- 2. Visual Testing is fast, uses low cost magnifiers and lighting.**
- 3. Visual Testing is not affected by COPV color, reflectivity or finish.**
- 4. Shearography detects any non-homogeneity in the COPV composite or liner that leads to local changes in the surface strain. Such defects include:**
  - **Fiber breakage, surface and subsurface matrix cracking**
  - **Degradation of composite matrix due to chemical or UV exposure.**
  - **Design or manufacturing flaws such as poor fiber closure pattern at bosses, bridging at transitions such as those at dome to cylinder areas.**
- 5. Shearography NDE requires relatively expensive equipment, operator training, part stability and fixture.**
- 6. Shearography is affected by and procedures must accommodate COPV color, reflectivity and glare.**

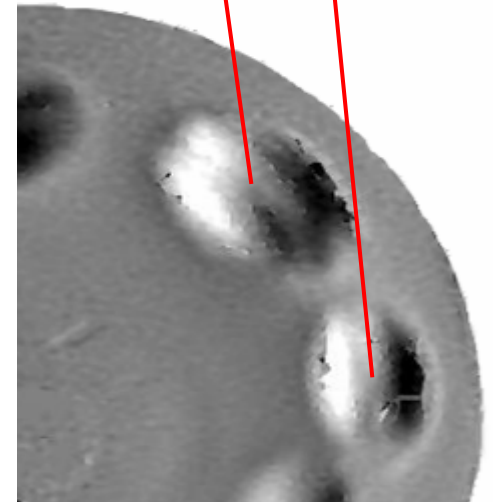




**Visual impact damage for the graphite COPV ranged from severe fracture seen below, enhanced with dye penetrant coating, to little or no discernable damage beyond the very small, 0.1-0.2 inch impact sites seen on 10 ¼ inch COPV at right.**



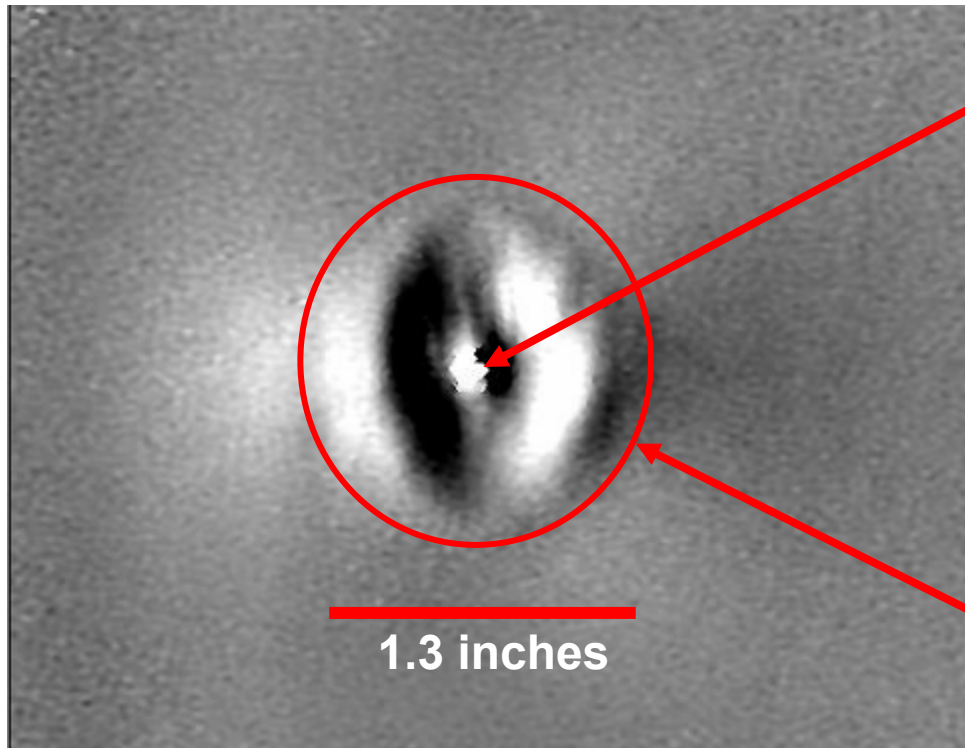
**Shearography image of area on the 10 ¼ inch COPV above.**



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# Shearography and Visual Indications of COPV Impact Damage



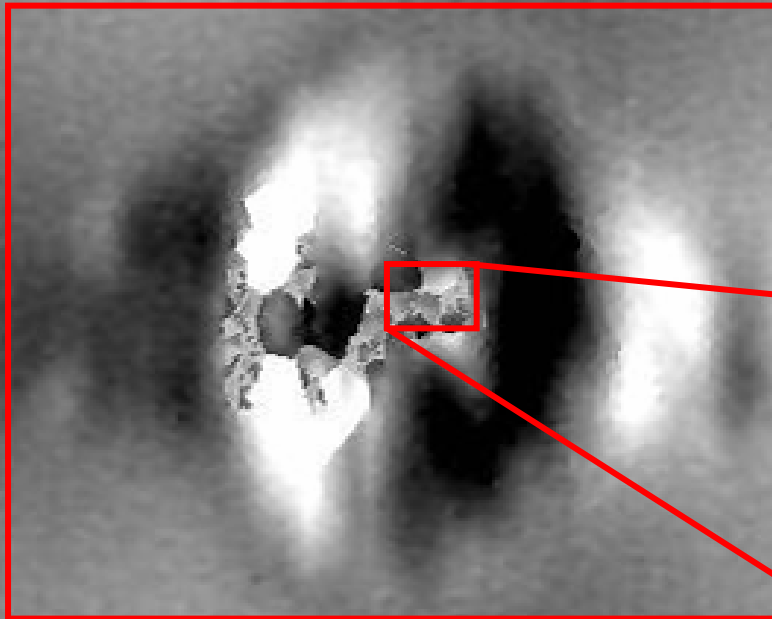
**Impact Site for intentional Defects are seen visually as dimple, fiber breakage and/or color change.**

**Visual indication of composite damage ranged from severe fracturing at area around impact site to a small crack or dimple, to no visual indication.**

**Shearography indications seen in graphite COPV ranged from 0.2 to 4 inches in diameter.**



**Shearography Damage Indication  
Measures 4.1 inches**



**Comparison Between The  
Measured Shearography  
Damage Dimensions and  
Visual Damage of 50 Ft-Lb  
Impact @ 180°, 10 Inches  
from Forward Boss**



**Visual Damage  
Measured 0.5 in.**

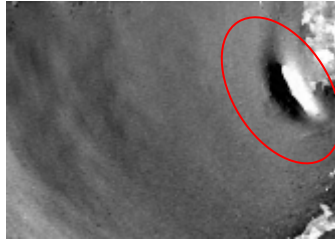
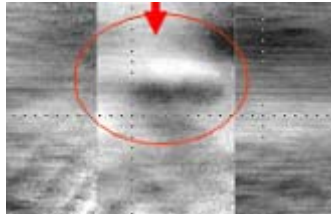
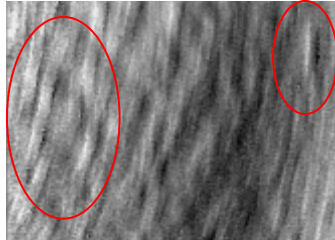
## **Section 8.0**

# **Defect Guide to Found Shearography Indications in Tested COPV**



# Defect Guide to Found Shearography Indications in Tested COPV

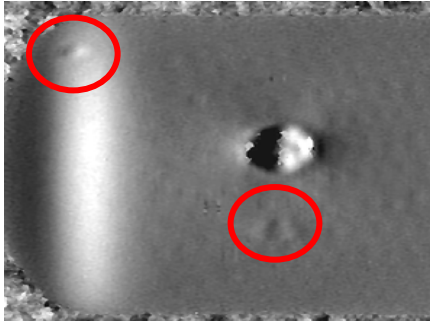

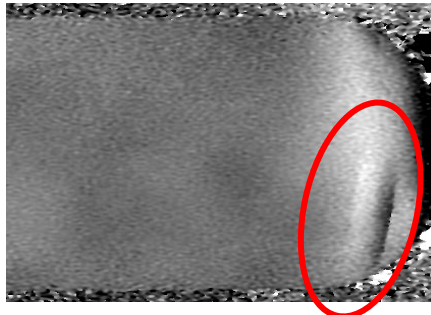
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<b>Kevlar COPV Indication Type</b>		<b>Pages</b>	<b>S/N</b>
<b>1. Strain Concentrations at Boss - 10¼ in. Kevlar Sphere</b>		<b>66,76</b>	<b>003 004</b>
<b>2. Stain Concentrations at Girth Weld - 26 in. Kevlar Sphere</b>		<b>38,49</b>	<b>001</b>
<b>3. Fiber Delamination - 26 in Kevlar Sphere</b>		<b>45</b>	<b>005</b>

# Defect Guide to Found Shearography Indications in Tested COPV

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## Graphite COPV Indications

		Pages	S/N
1. Unintentional Damage 6x22 in. Cylinder		91,92,93,94	015
1. Cracks Due to Impact 6x22 in. Cylinder	 <p>Shear image shows crack 5 inches in length.</p>	101	063
1. Fiber Bridging at Transitions		105,106,107	139



# **Kevlar COPV Shearography Test Results**

## **Space Shuttle Kevlar COPV**

- |                           |         |
|---------------------------|---------|
| • 26 Inch Kevlar Sphere   | s/n 001 |
| • 26 Inch Kevlar Sphere   | s/n 005 |
| • 18 Inch Kevlar Sphere   | s/n 001 |
| • 18 Inch Kevlar Sphere   | s/n 004 |
| • 10 ¼ Inch Kevlar Sphere | s/n 001 |
| • 10 ¼ Inch Kevlar Sphere | s/n 003 |
| • 10 ¼ Inch Kevlar Sphere | s/n 012 |
| • 10 ¼ Inch Kevlar Sphere | s/n 014 |
| • 10 ¼ Inch Kevlar Sphere | s/n 015 |
| • 10 ¼ Inch Kevlar Sphere | s/n 019 |



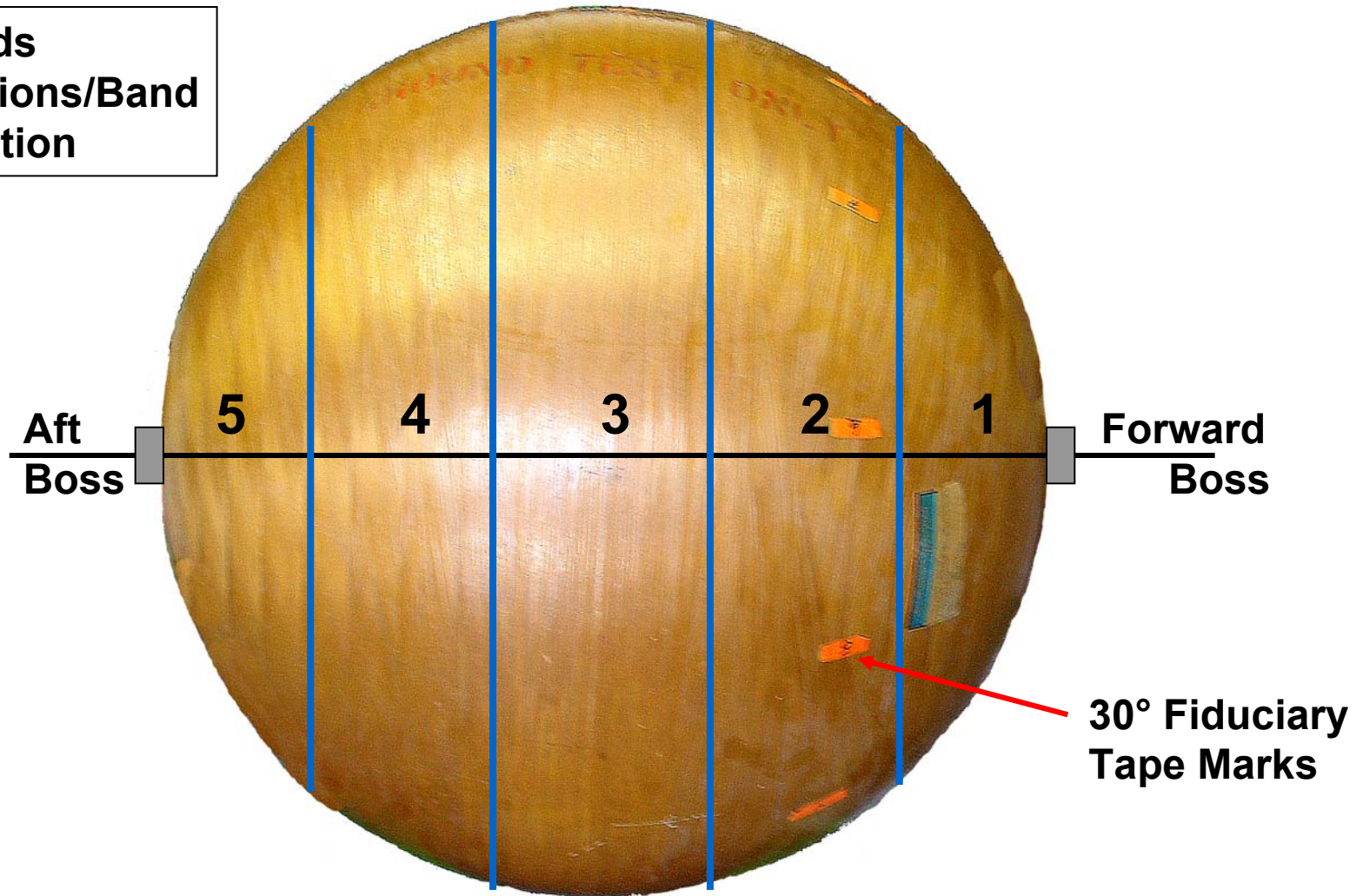
# **Shearography COPV Test Data**

## **26 Inch Kevlar Sphere s/n 001**



# 26 Inch Kevlar Sphere Scan Plan

**5 Bands**  
**12 Sections/Band**  
**30°/Section**



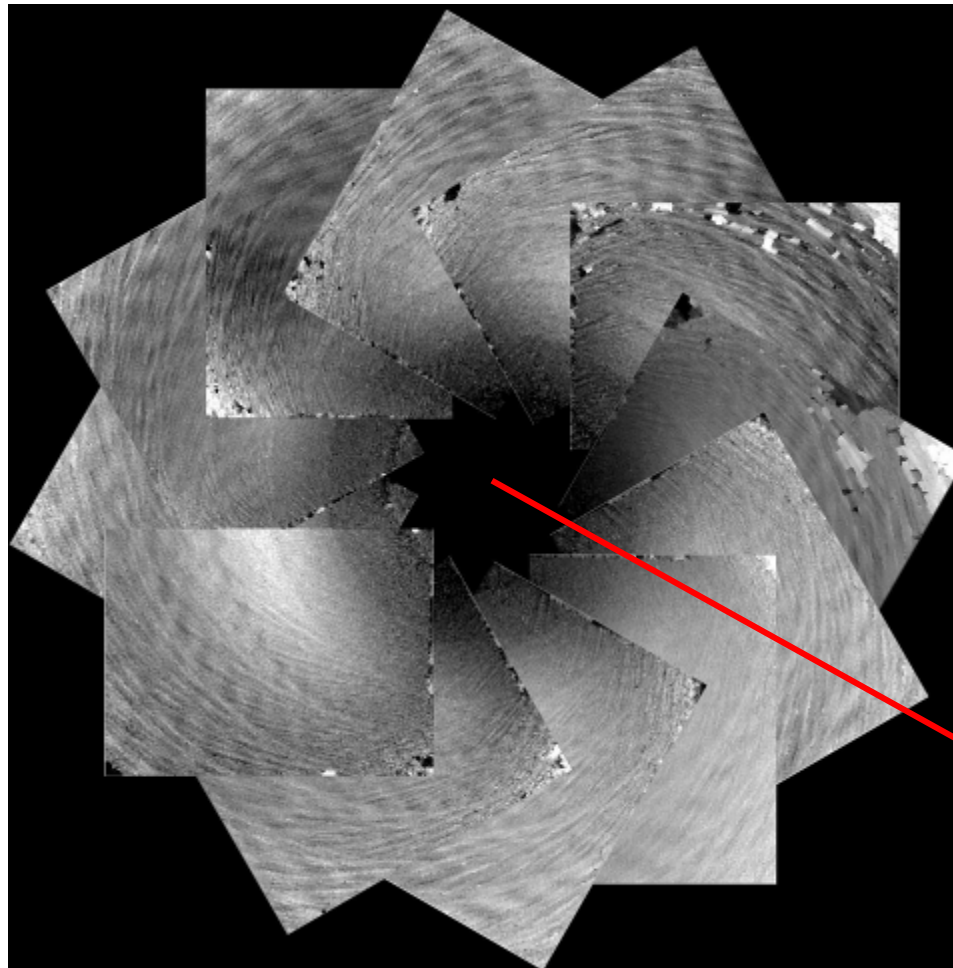


# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 001

## Band 1 Forward Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

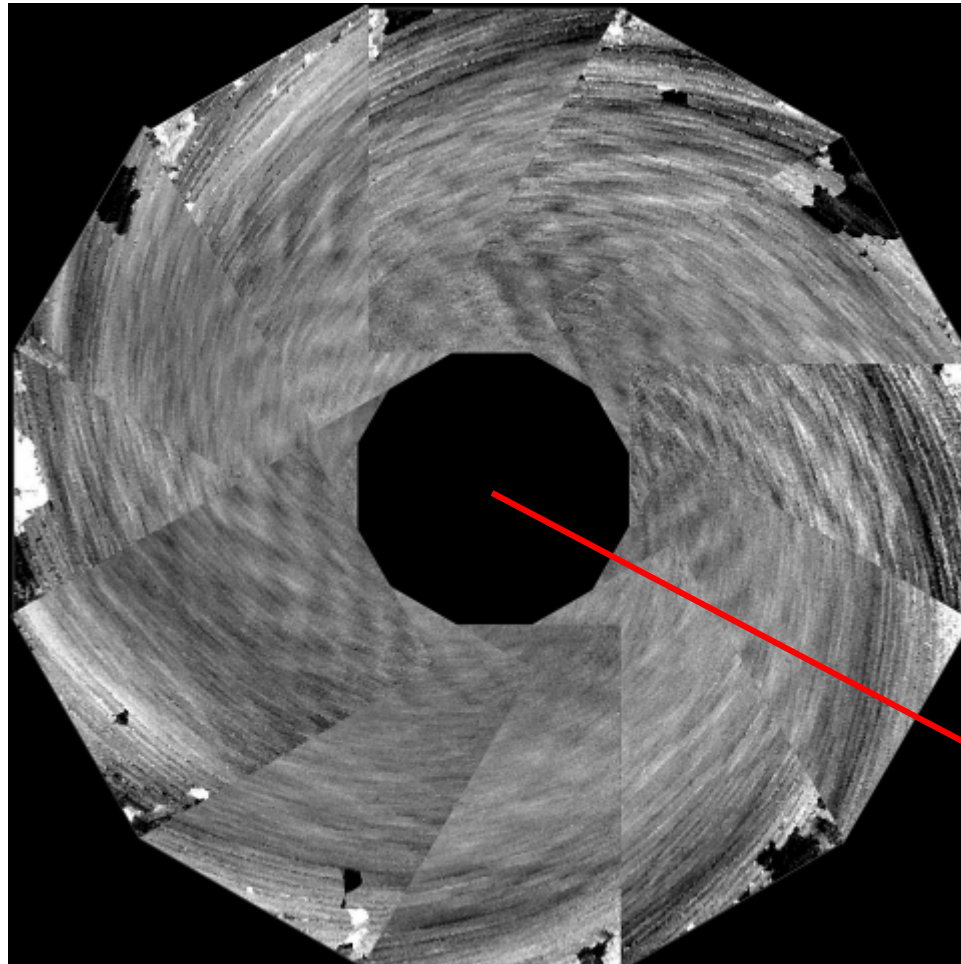


# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 001

## Band 2 Forward Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

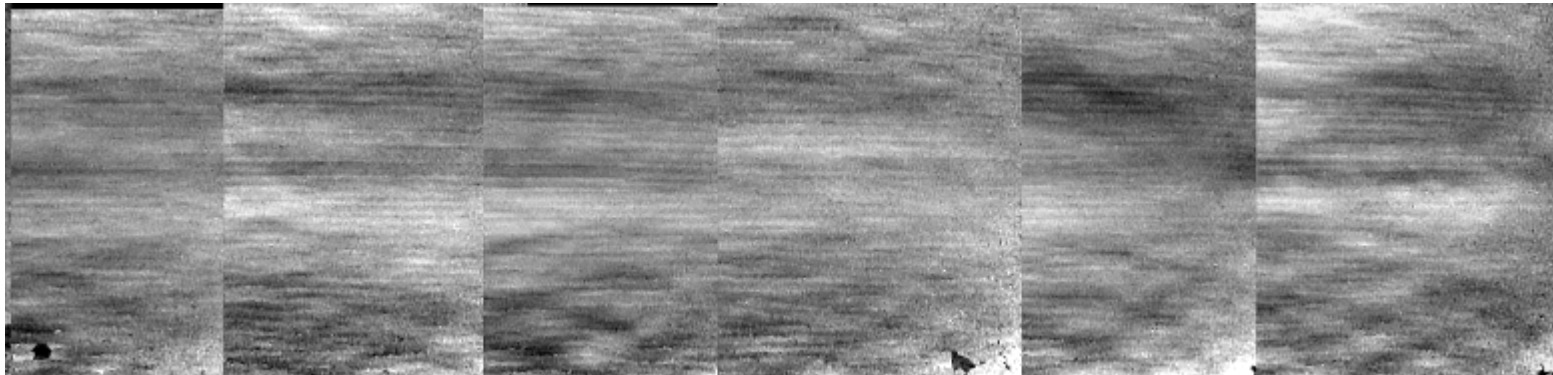
# Shearography COPV Test Data

26 Inch Kevlar Sphere s/n 001

## Band 3 Equator Over Circumferential Girth Weld

0°

180°

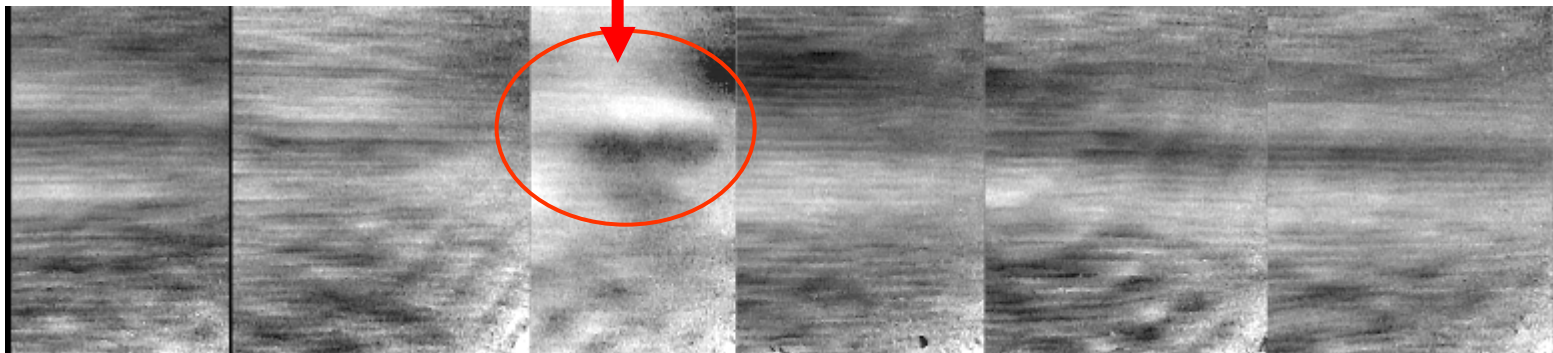


180°

255°

**Stress Concentration**

360°

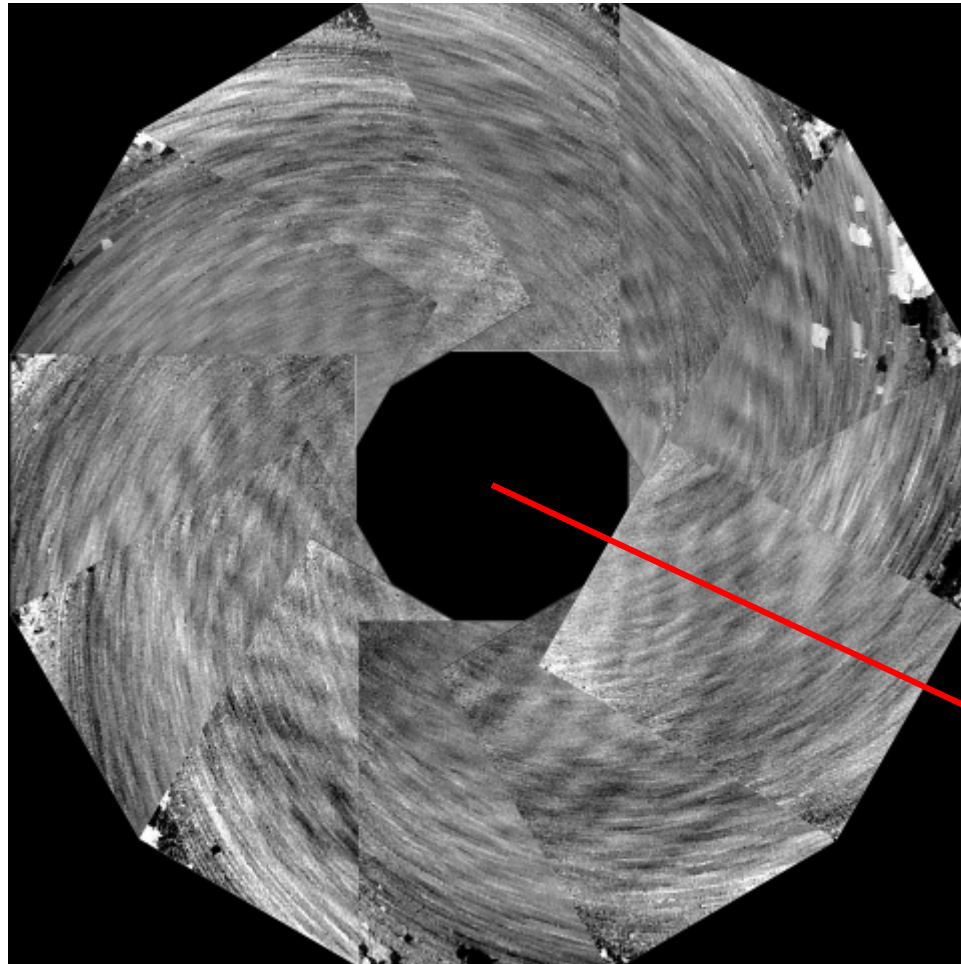


# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 001

## Band 4 Forward Boss End



**Results:  
No Anomaly  
Indications  
Detected**

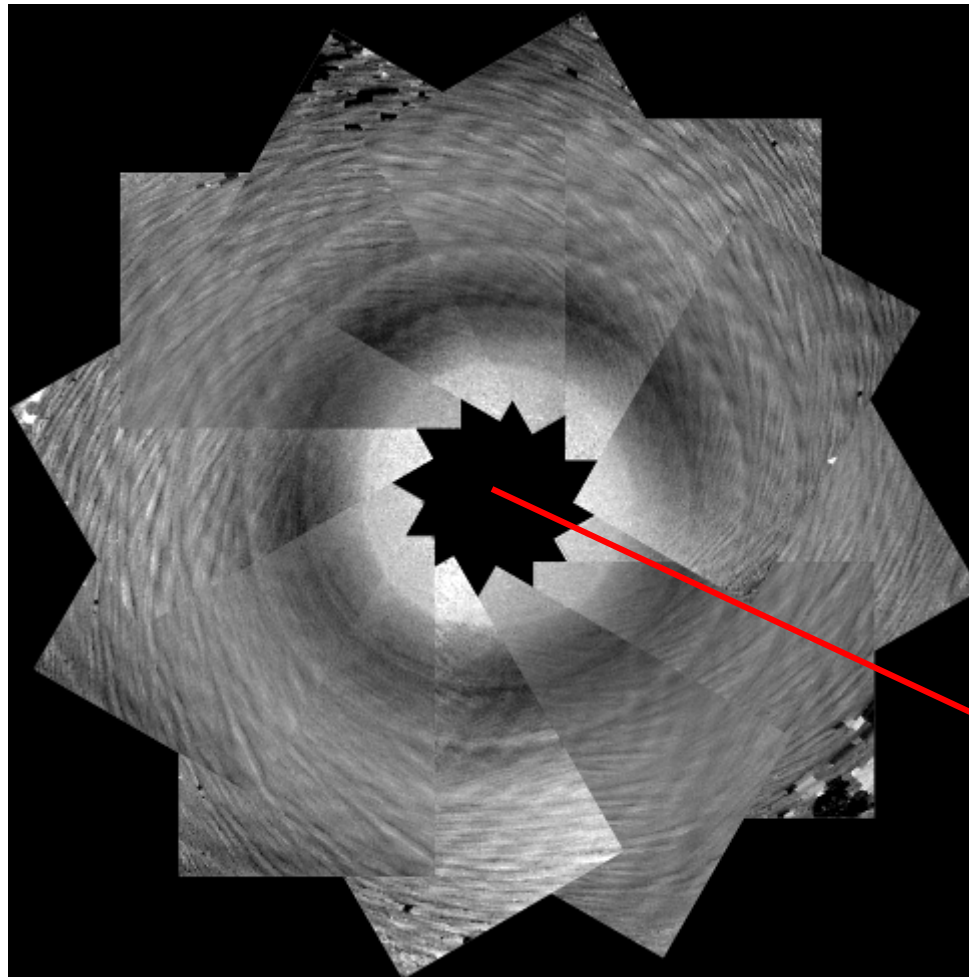
0°

# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 001

## Band 5 Aft Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# **Shearography COPV Test Data**

**26 Inch Kevlar Sphere  
s/n 005**



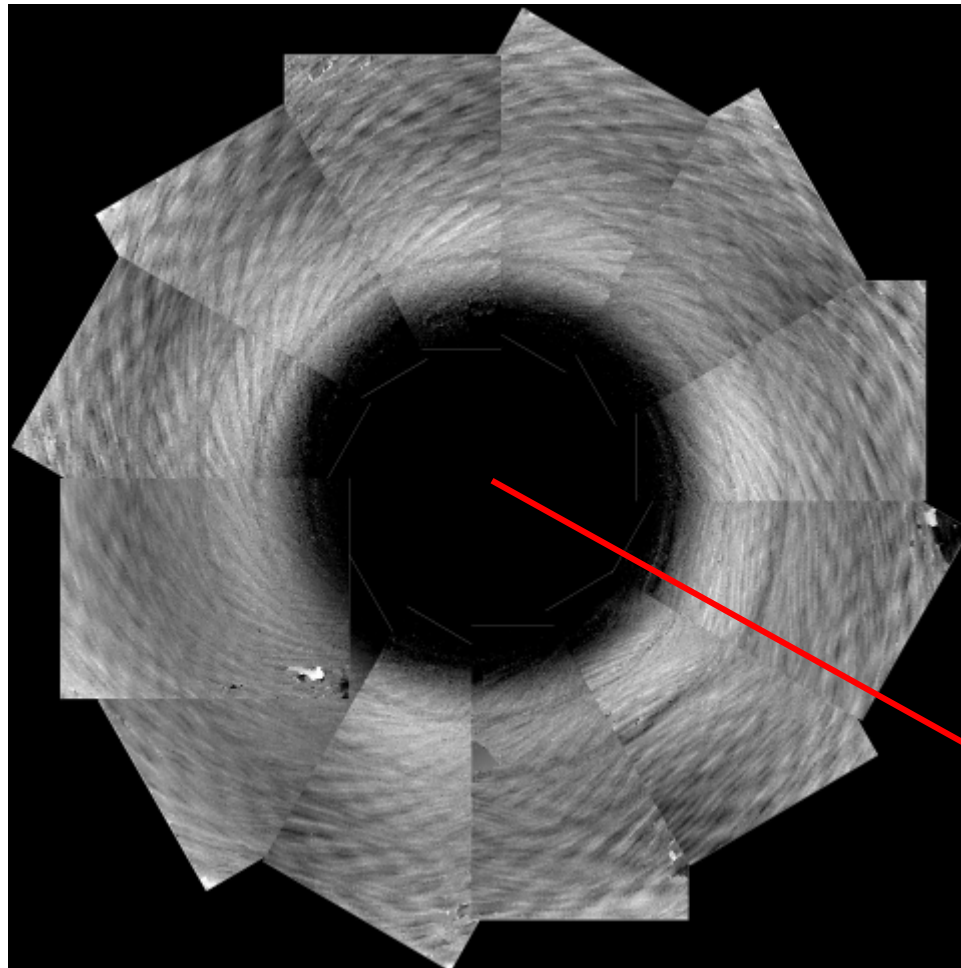


# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 005

## Band 1 Forward Boss End



**Results:  
No Anomaly  
Indications  
Detected**

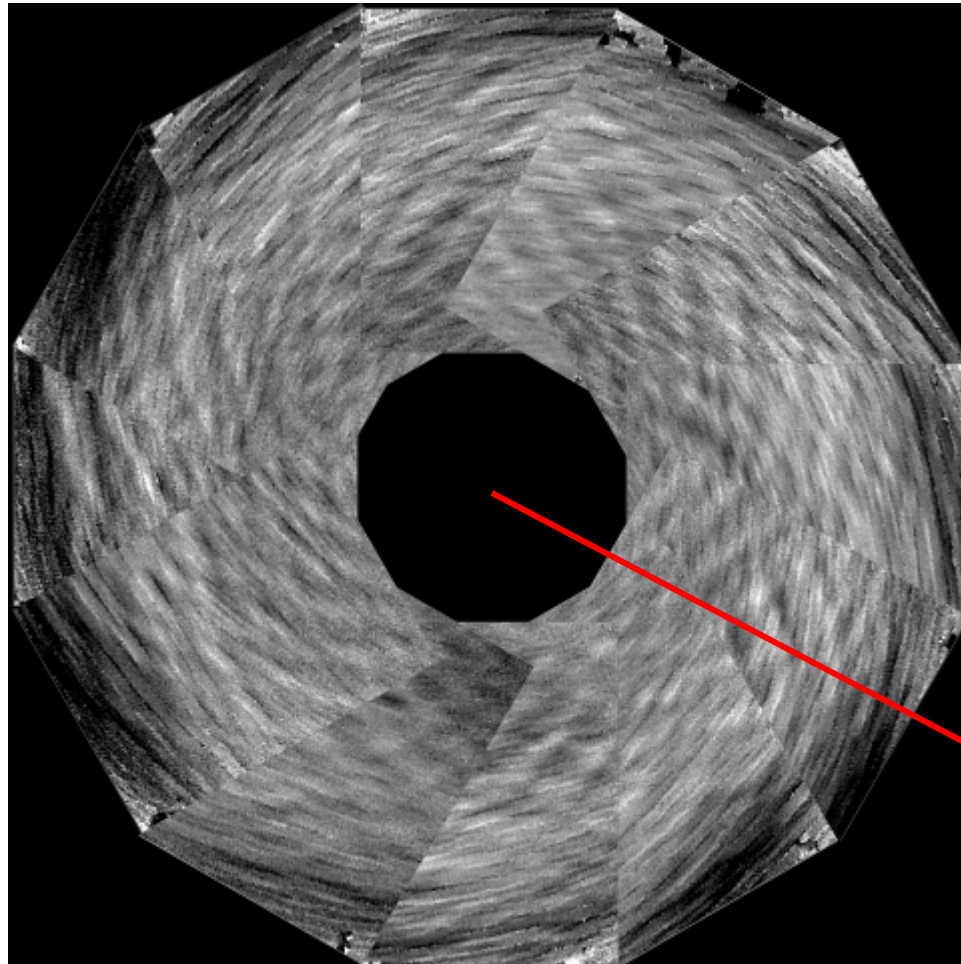
0°

# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 005

## Band 2 Forward Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# Shearography COPV Test Data

26 Inch Kevlar Sphere

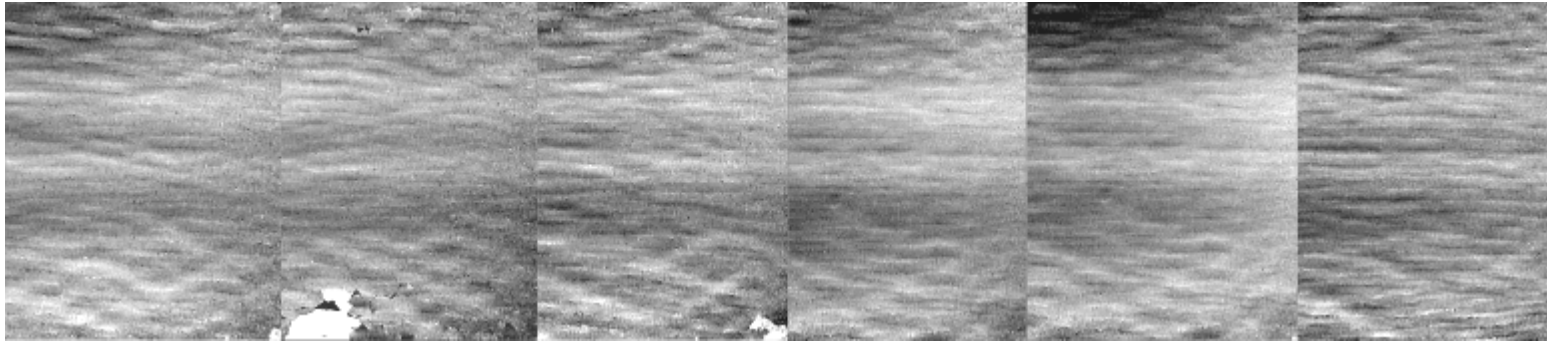
s/n 005

**Results:  
No Anomaly  
Indications  
Detected**

## Band 3 Equator Over Circumferential Girth Weld

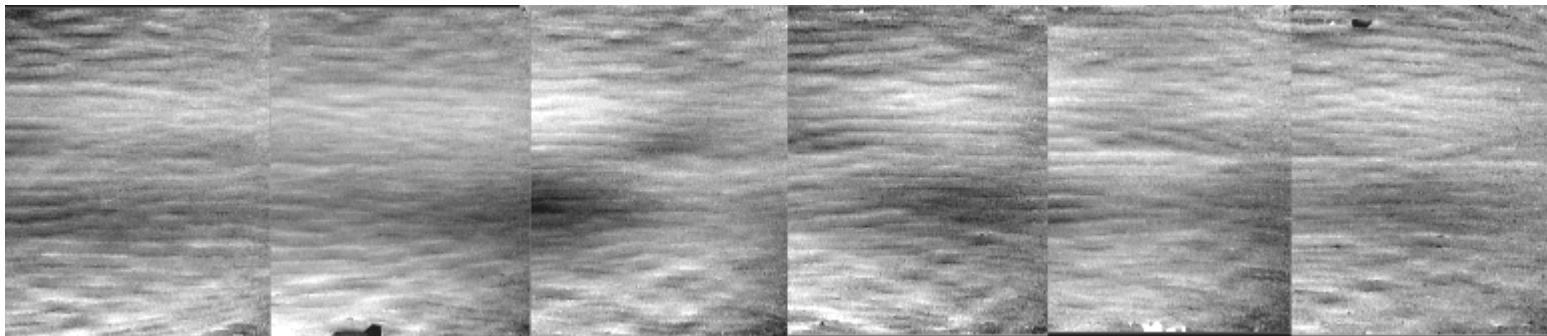
0°

180°



180°

360°

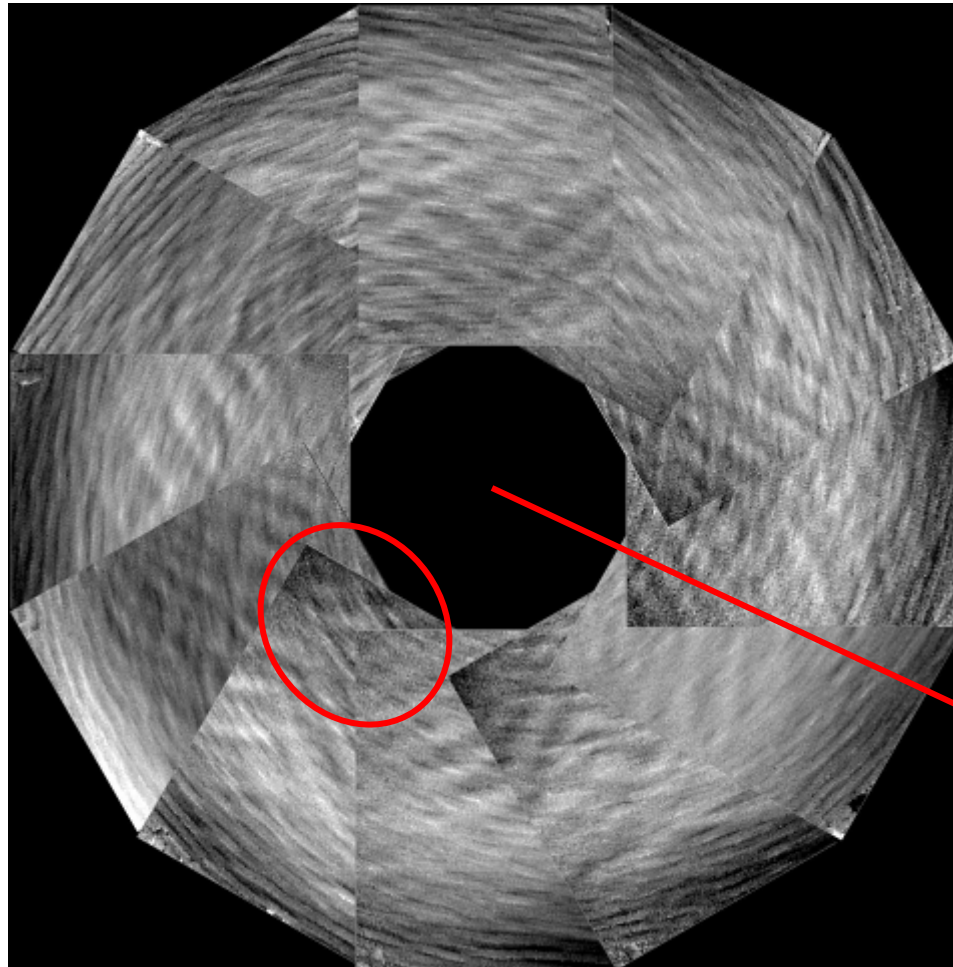


# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 005

## Band 4 Forward Boss End



**Results:  
Fiber  
Delaminations  
Detected @  
Approx. 240°**

**0°**

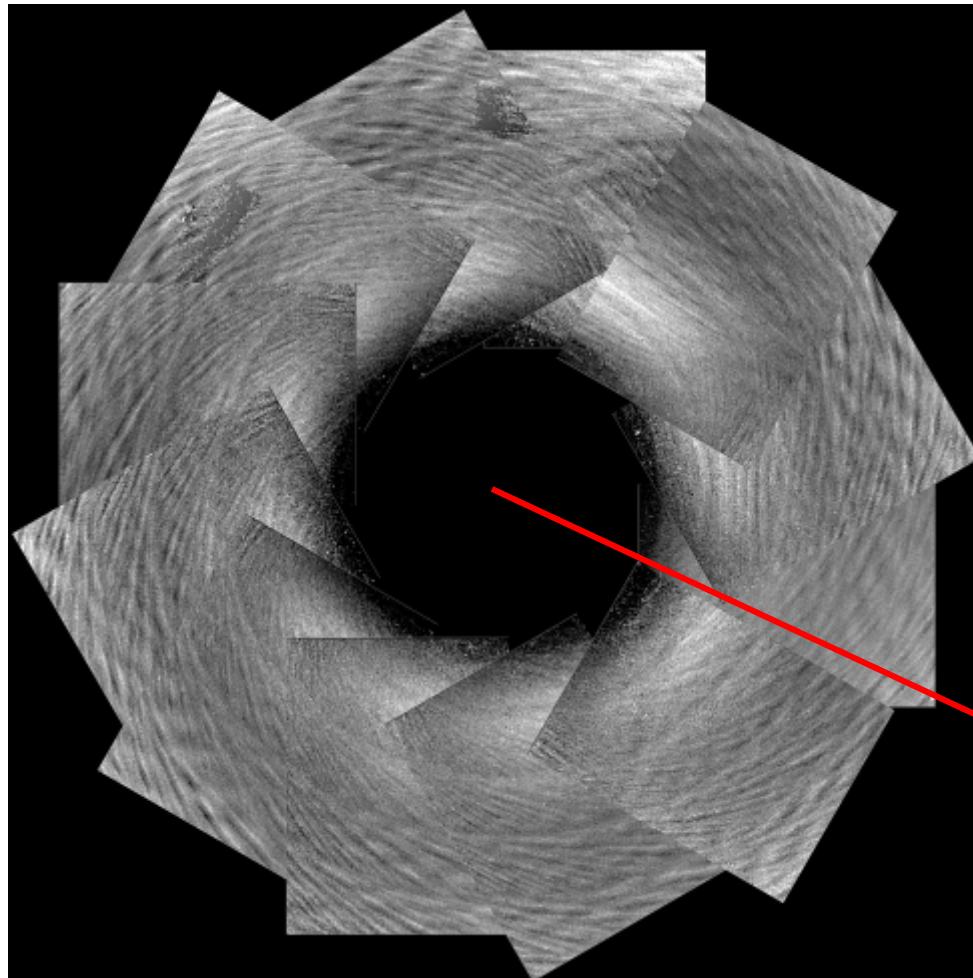


# Shearography COPV Test Data

26 Inch Kevlar Sphere

s/n 005

## Band 5 Aft Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°



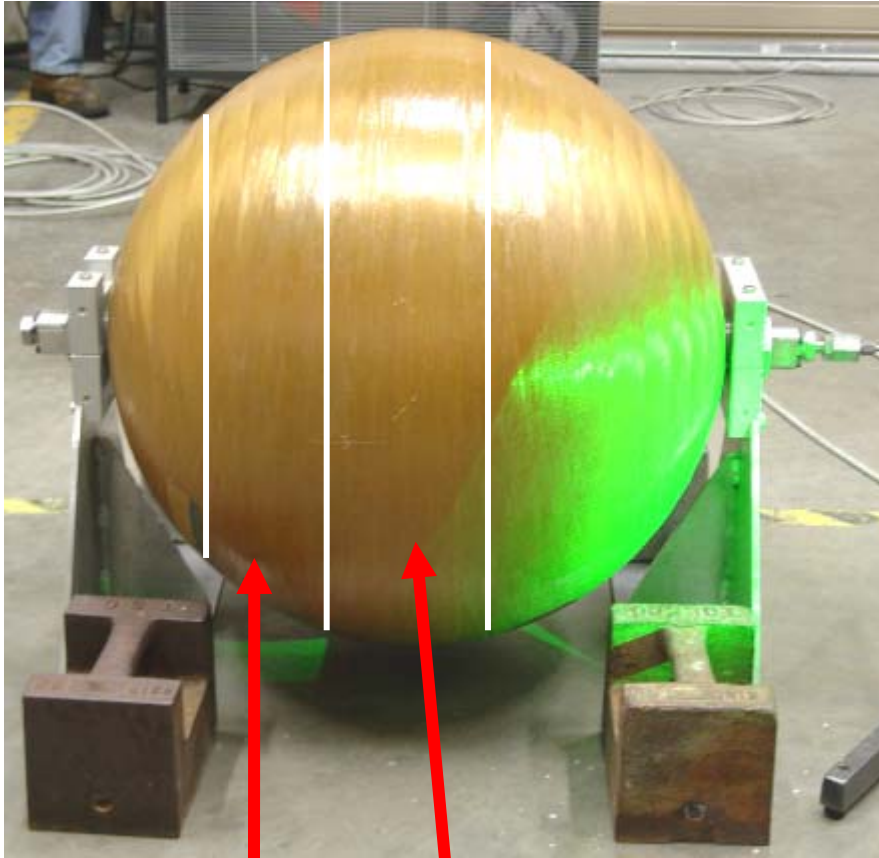
# **Summary Shearography COPV Test Results**

**26 Inch Kevlar Sphere  
s/n 001  
s/n 005**



# Shearography Inspection of 26 Inch Kevlar COPV

## Band 3 – Equator, Over Circumferential Girth Weld



Band 4      Band 3 Equator

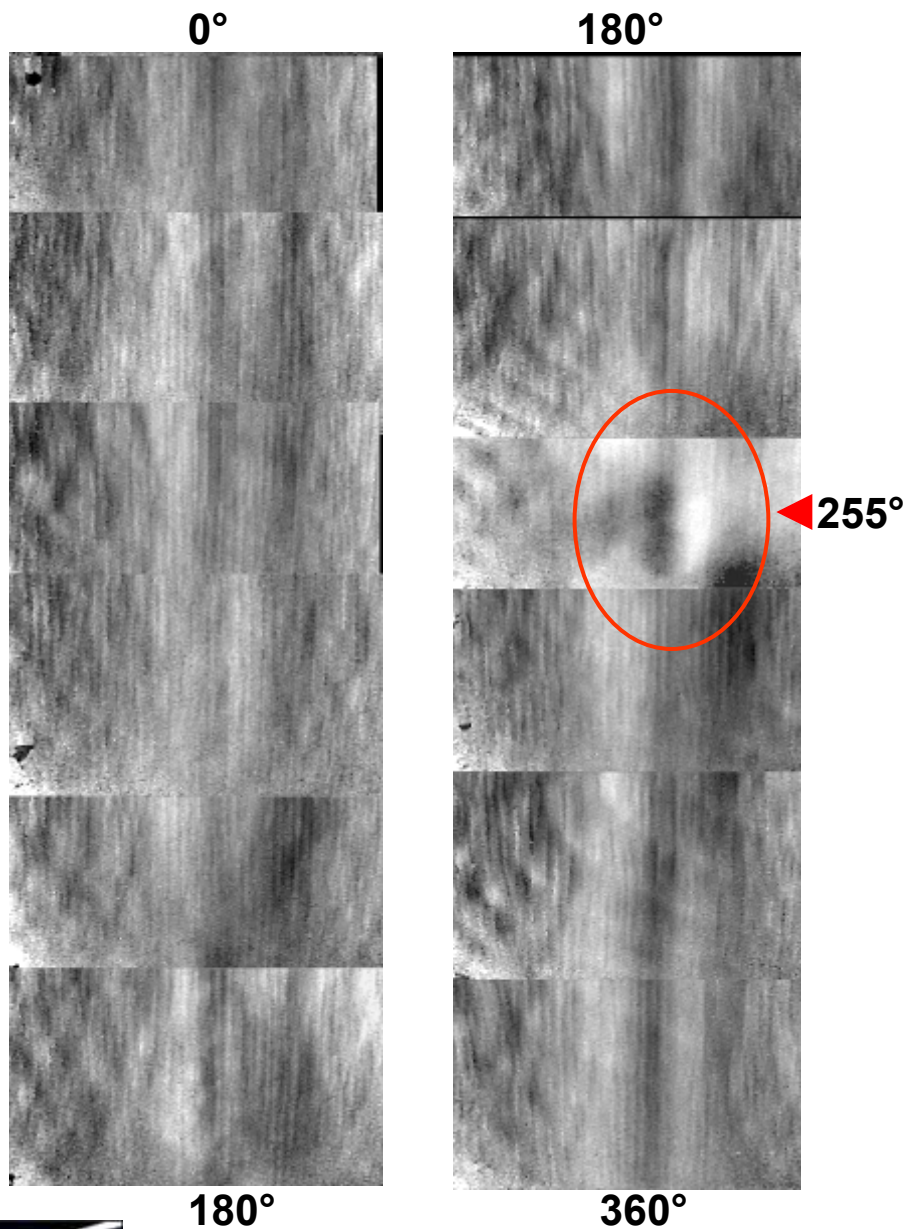
- Pressure Shearography inspected with 20 psid.
- COPV s/n 001 and 005 tested.

### Test Results:

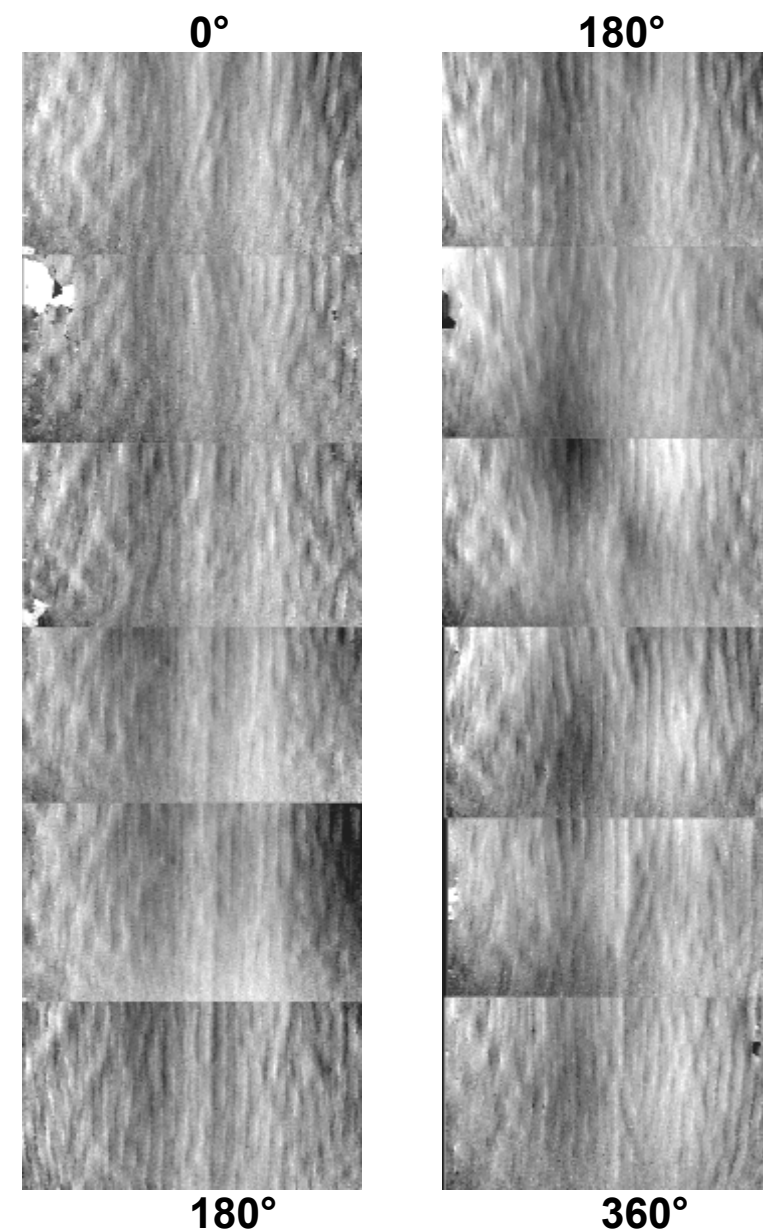
s/n 001  
Strain concentration @255°

s/n 005  
Fiber Delaminations Detected  
Band 4 @ approx. 240°

26 Inch Kevlar COPV Fleet Leader s/n 001



26 Inch Kevlar COPV Fleet Leader s/n 005



# **Shearography COPV Test Data**

## **18 Inch Kevlar Sphere s/n 001**



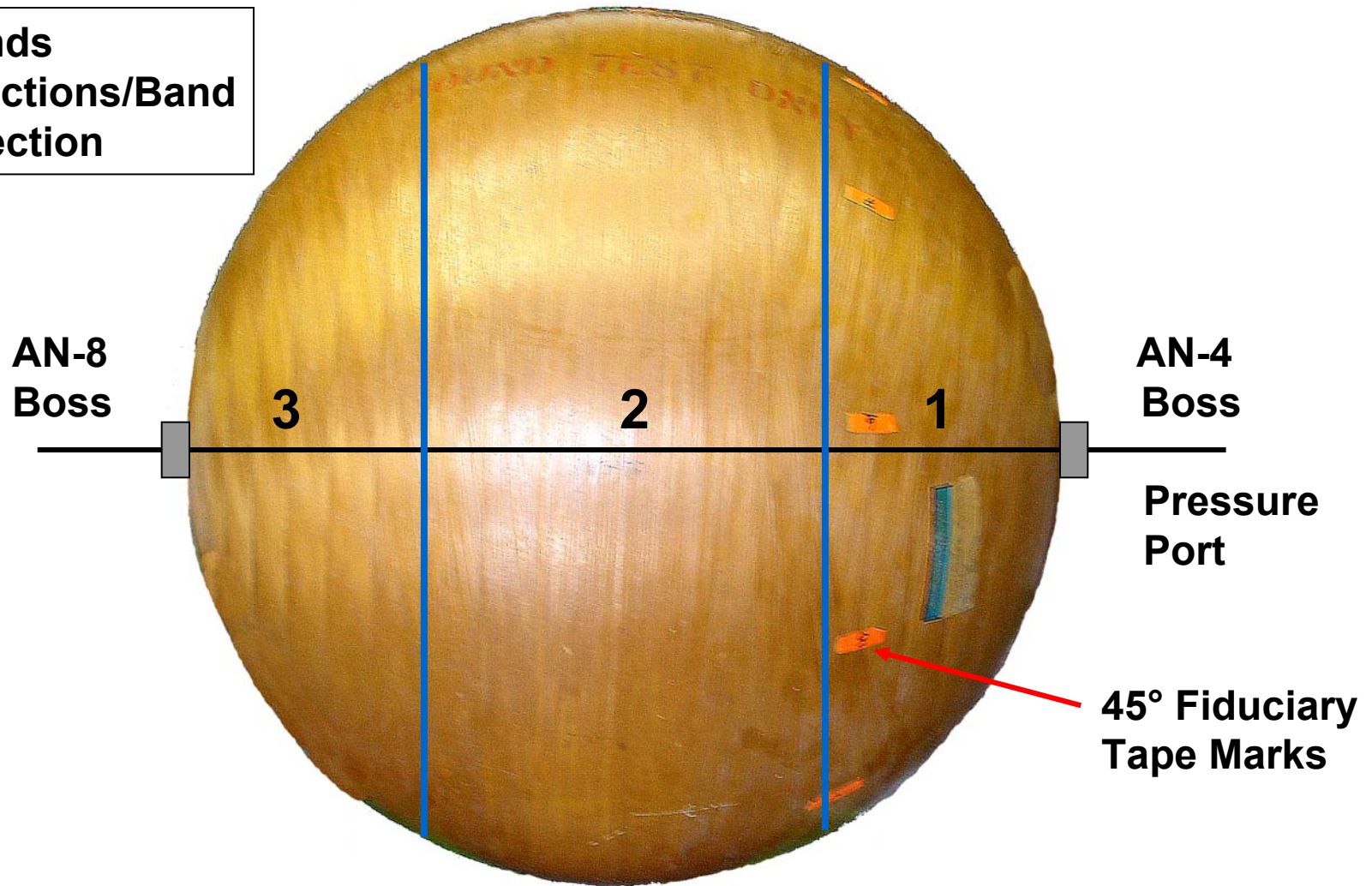
# 18 Inch Kevlar Sphere Test Fixture





# 18 Inch Kevlar Sphere Scan Plan

**3 Bands**  
**10 Sections/Band**  
**36°/Section**

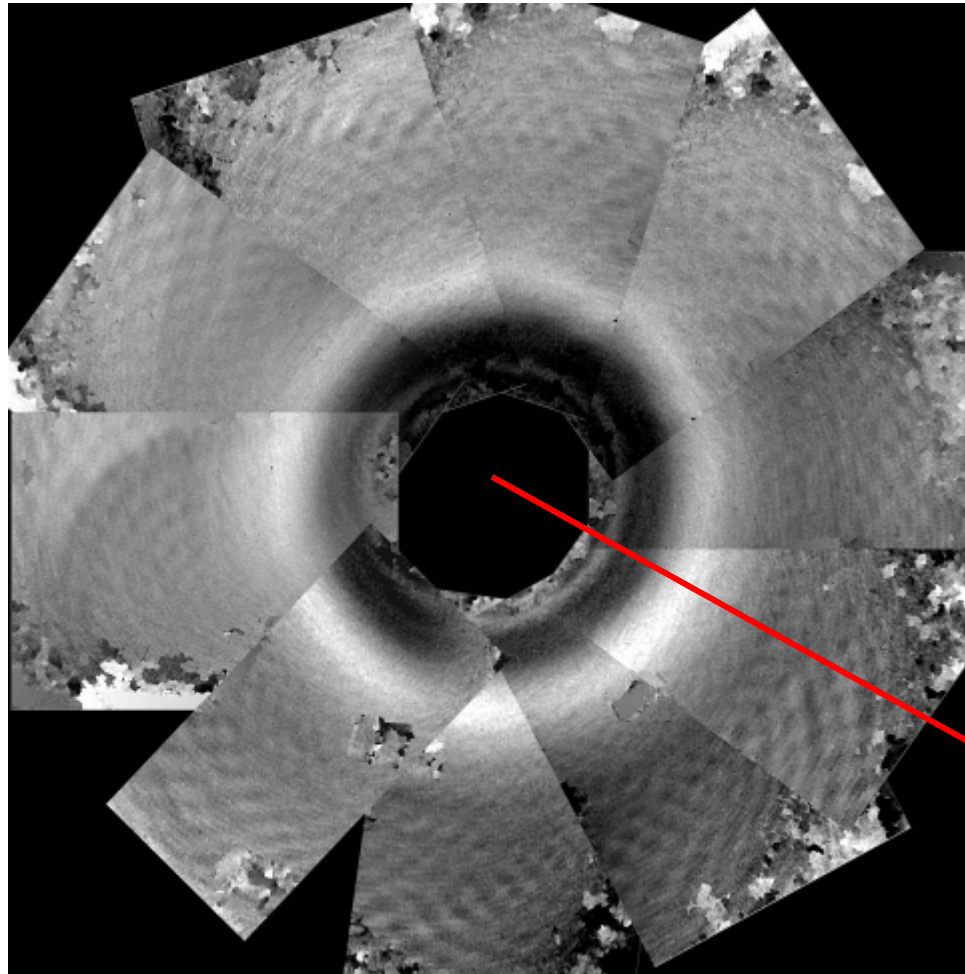


# Shearography COPV Test Data

18 Inch Kevlar Sphere

s/n 001

## Band 1 AN-4 Boss (Pressure Port)



**Results:  
No Anomaly  
Indications  
Detected**

0°



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# Shearography COPV Test Data

18 Inch Kevlar Sphere

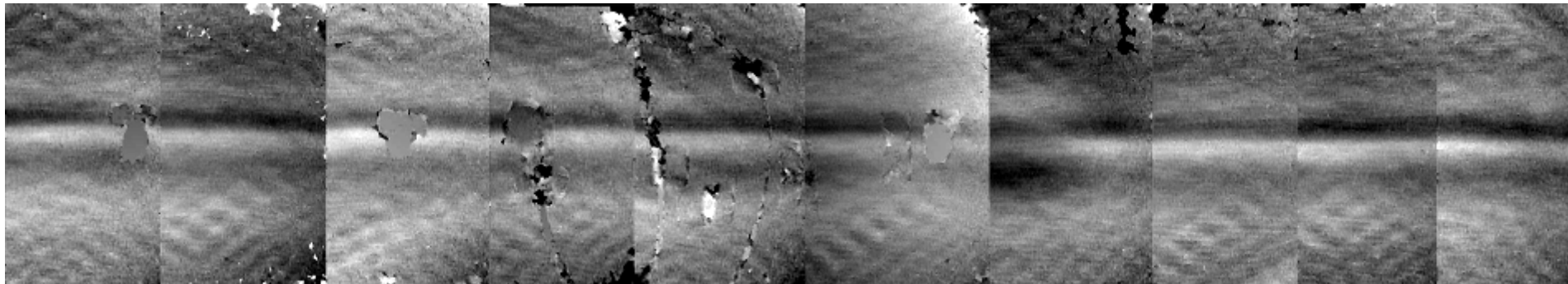
s/n 001

**Results:  
No Anomaly  
Indications  
Detected**

Band 2 Equator over Circumferential Girth Weld

0°

360°

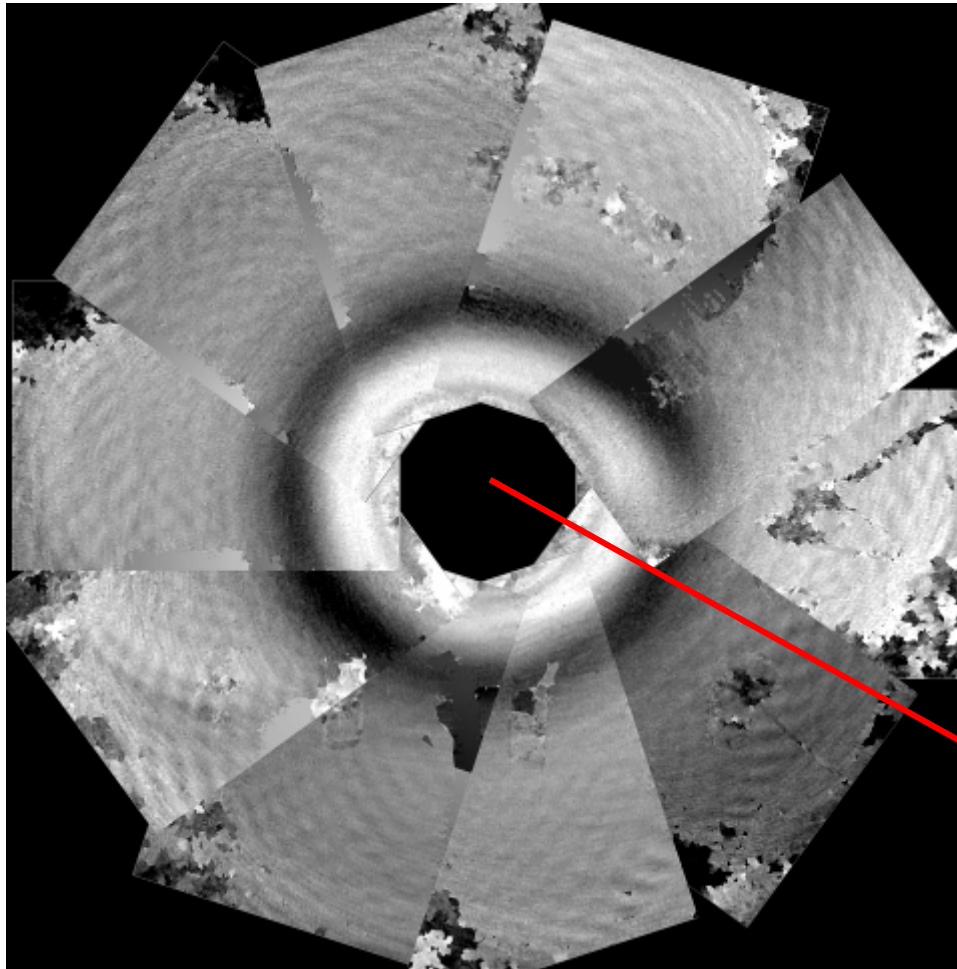


# Shearography COPV Test Data

18 Inch Kevlar Sphere

s/n 001

## Band 3 AN-8 Boss (Blank End)



**Results:  
No Anomaly  
Indications  
Detected**

**0°**

# **Shearography COPV Test Data**

## **18 Inch Kevlar Sphere s/n 004**



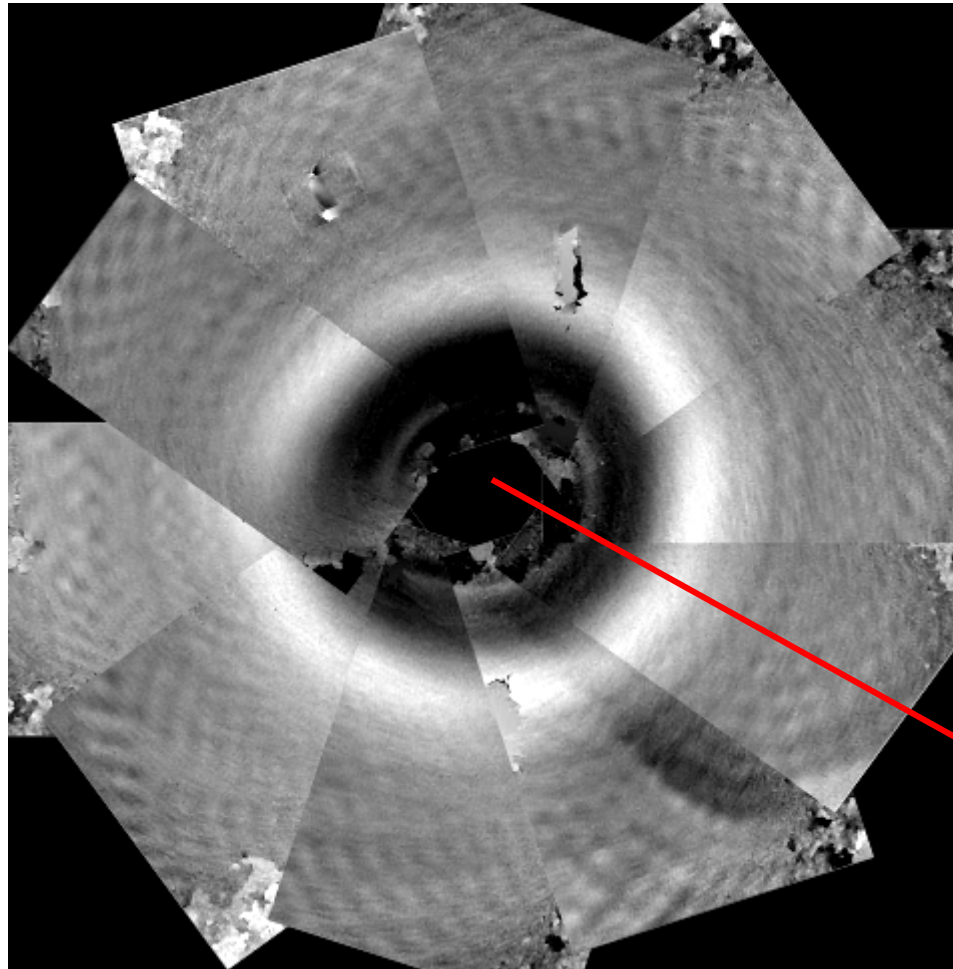


# Shearography COPV Test Data

18 Inch Kevlar Sphere

s/n 004

## Band 1 AN-4 Boss (Pressure Port)



**Results:  
No Anomaly  
Indications  
Detected**

0°



# Shearography COPV Test Data

18 Inch Kevlar Sphere

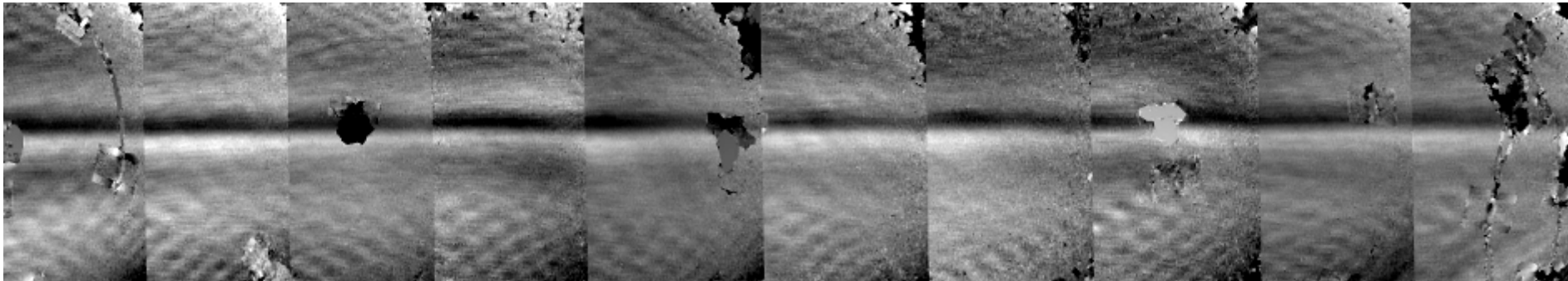
s/n 004

**Results:  
No Anomaly  
Indications  
Detected**

Band 2 Equator over Circumferential Girth Weld

0°

360°

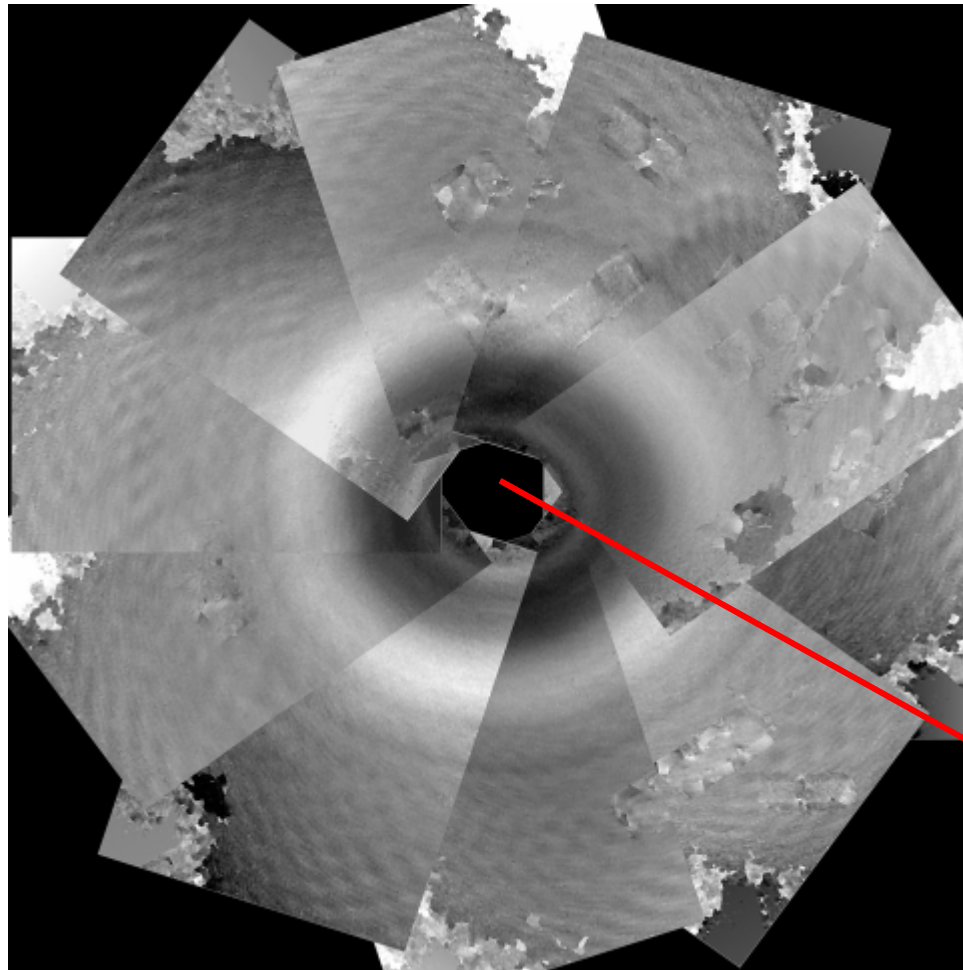


# Shearography COPV Test Data

18 Inch Kevlar Sphere

s/n 004

## Band 3 AN-8 Boss (Blank End)



**Results:  
No Anomaly  
Indications  
Detected**

0°

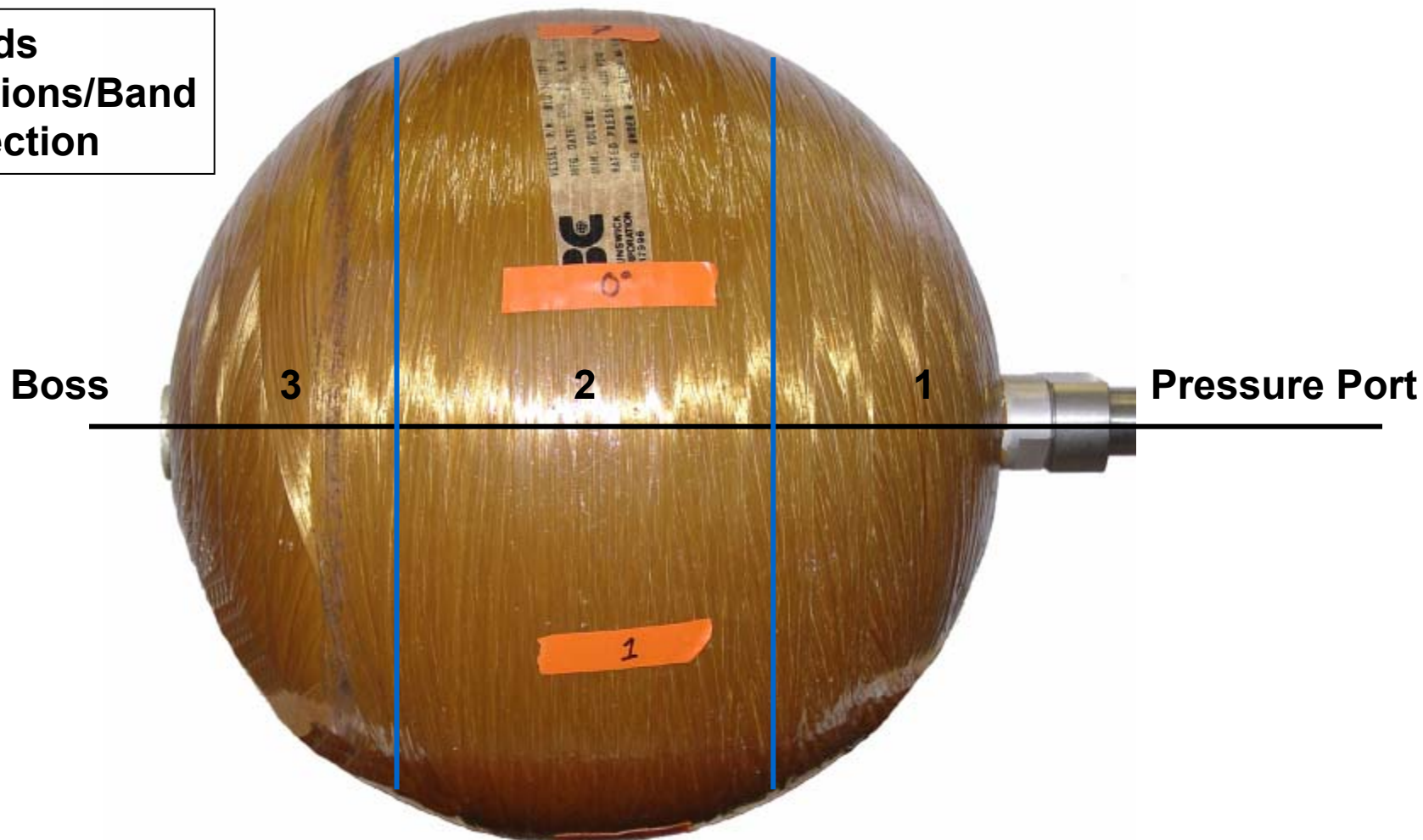
# **Shearography COPV Test Data**

**10 1/4 Inch Kevlar  
Sphere s/n 001**



# 10 ¼ Inch Kevlar Sphere Scan Plan

**3 Bands**  
**8 Sections/Band**  
**45°/Section**

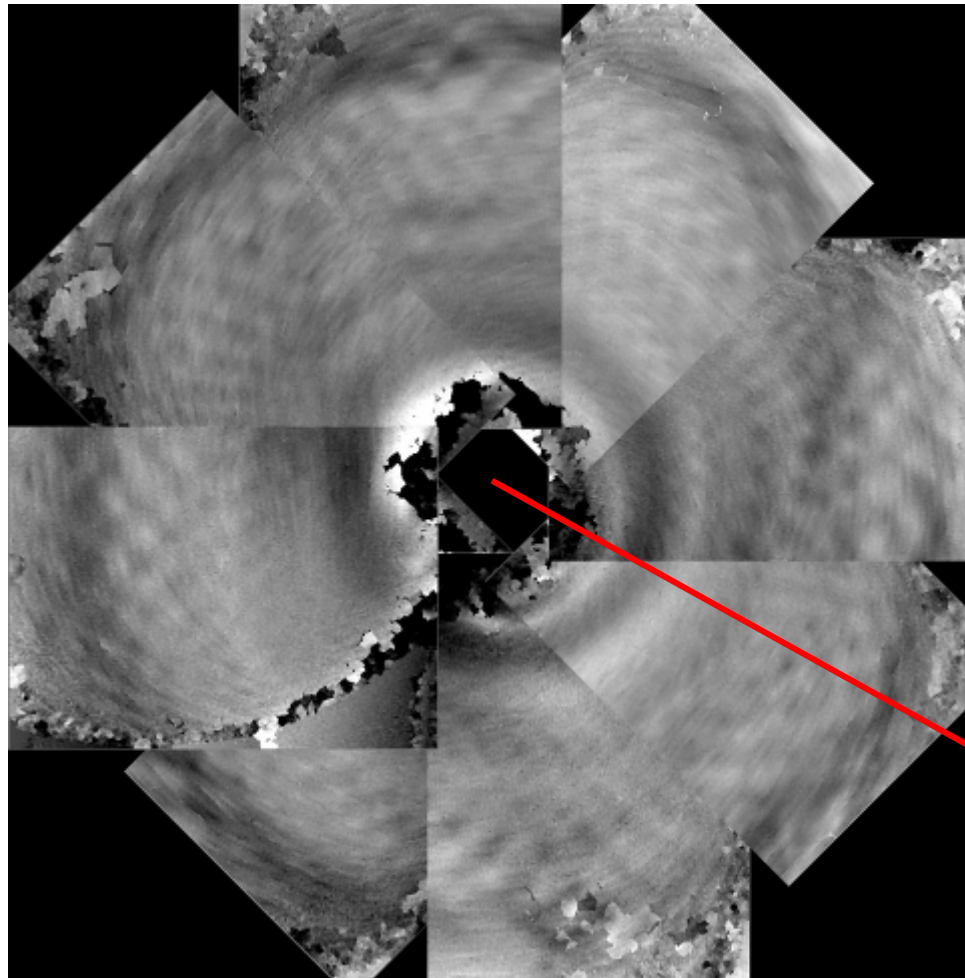


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 001

## Band 1 Pressure Port End



**Results:  
No Anomaly  
Indications  
Detected**

0°



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# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

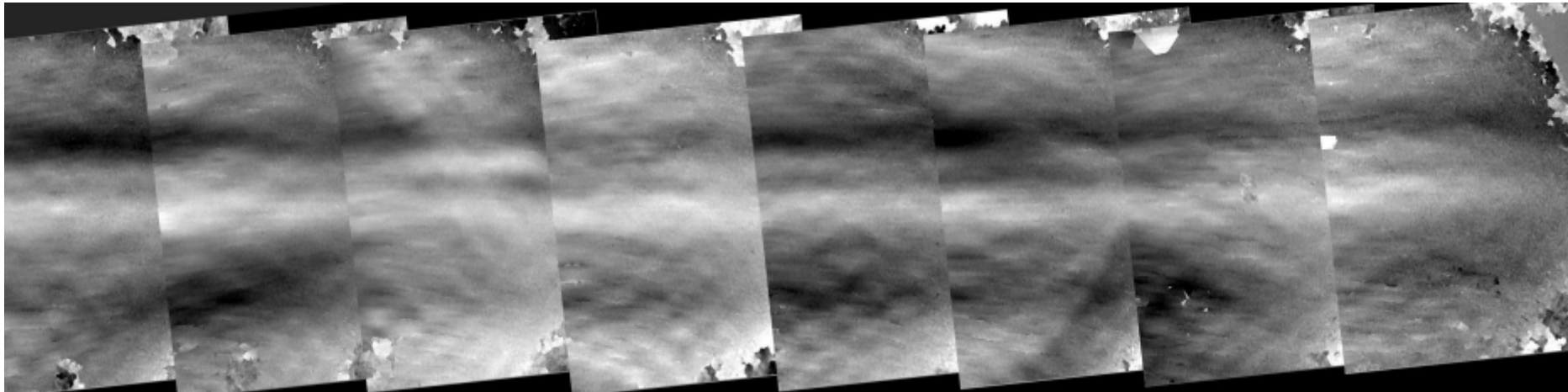
s/n 001

Band 2 Equator over Circumferential Weld

**Results:  
No Anomaly  
Indications  
Detected**

0°

360°

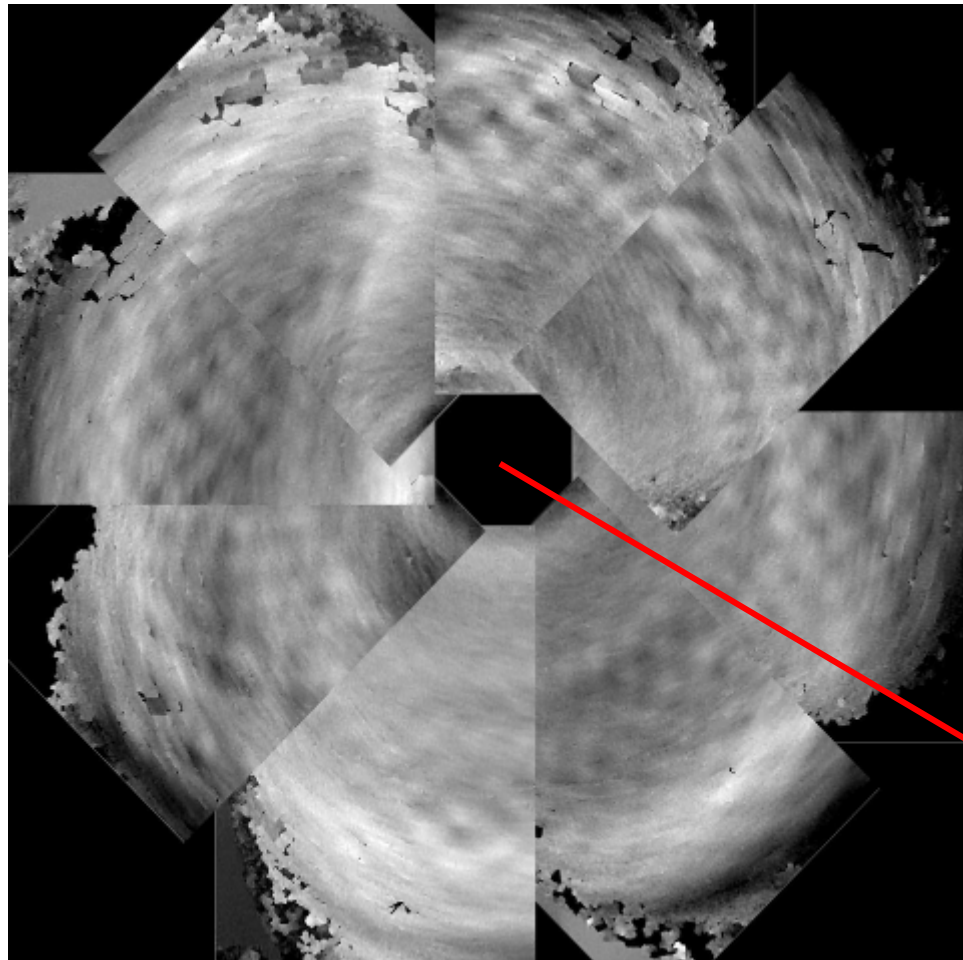


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 001

## Band 1 Pressure Port End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# **Shearography COPV Test Data**

**10 1/4 Inch Kevlar  
Sphere s/n 003**

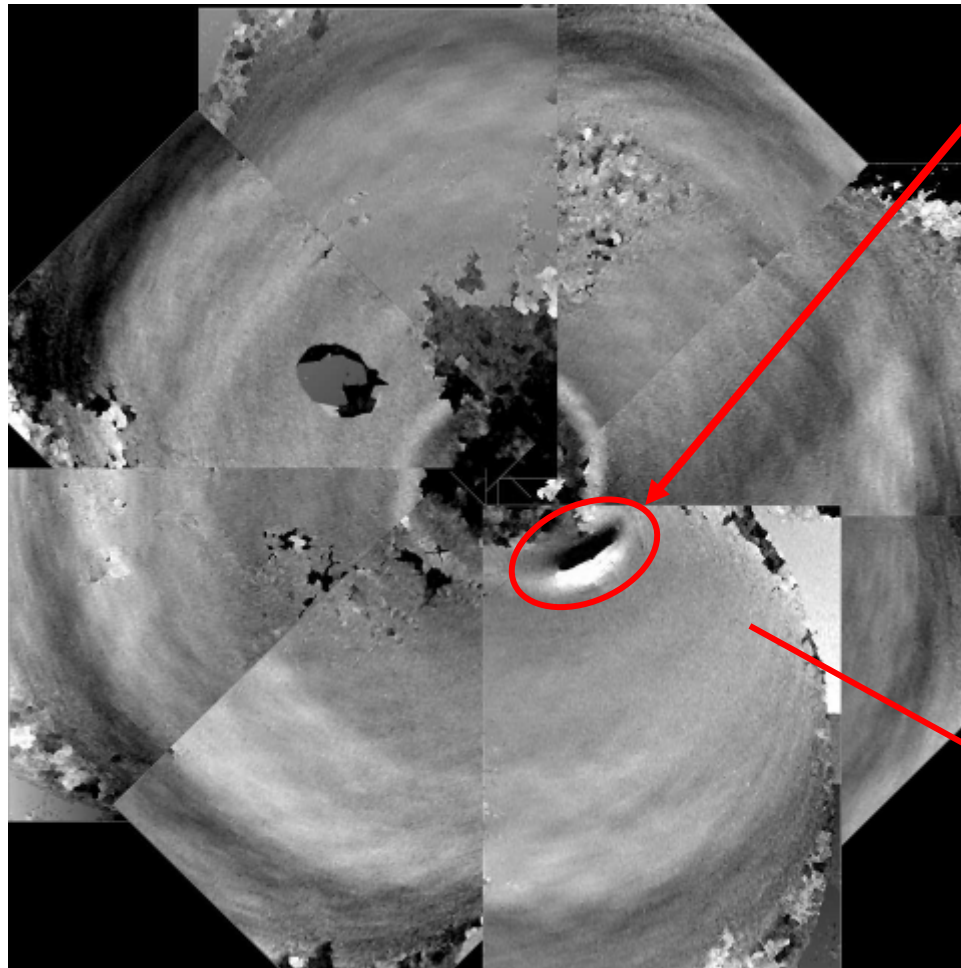


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 003

## Band 1 Pressure Port End



**Stress  
Concentration  
at Boss**

**Results:  
Anomaly  
Indications  
Detected.  
Unusually  
High Stress  
Concentration  
At Pressure  
Port Boss**

**0°**

# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

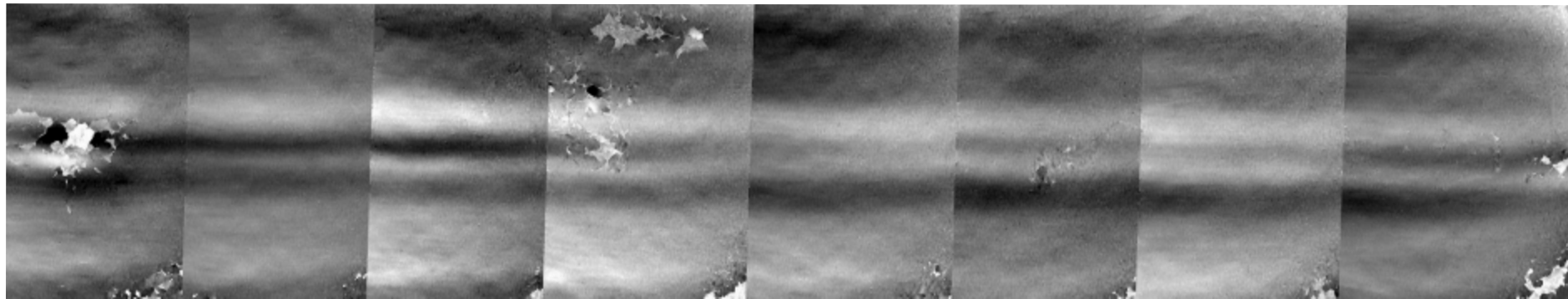
s/n 003

Band 2 Equator over Circumferential Weld

**Results:  
No Anomaly  
Indications  
Detected**

0°

360°



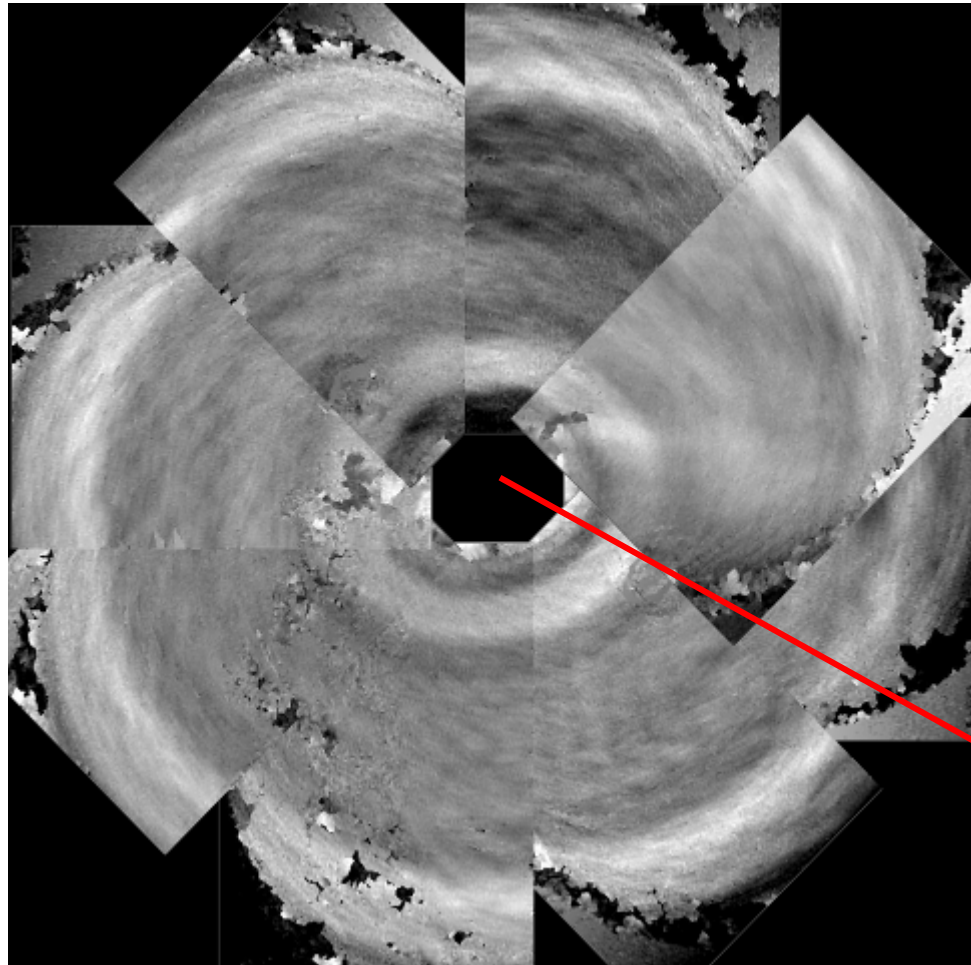


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 003

## Band 3 Blank Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# **Shearography COPV Test Data**

**10 1/4 Inch Kevlar  
Sphere s/n 012**

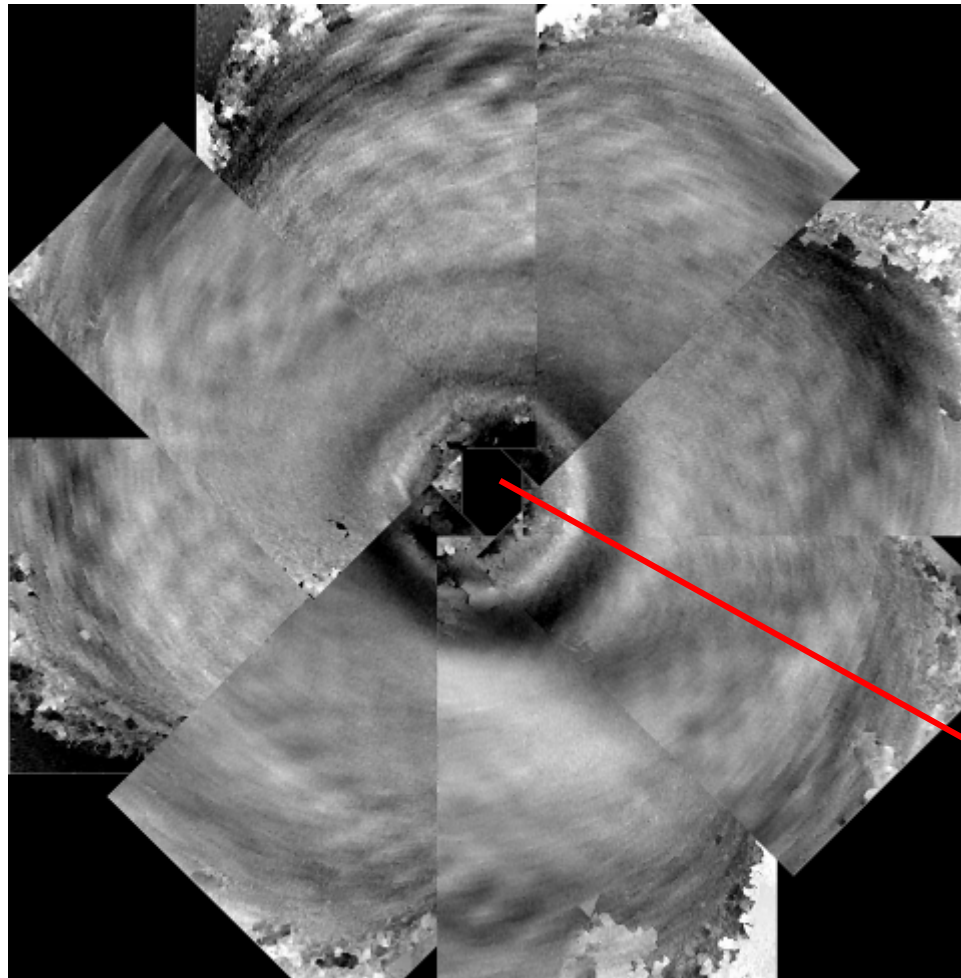


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 012

## Band 1 Pressure Port End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

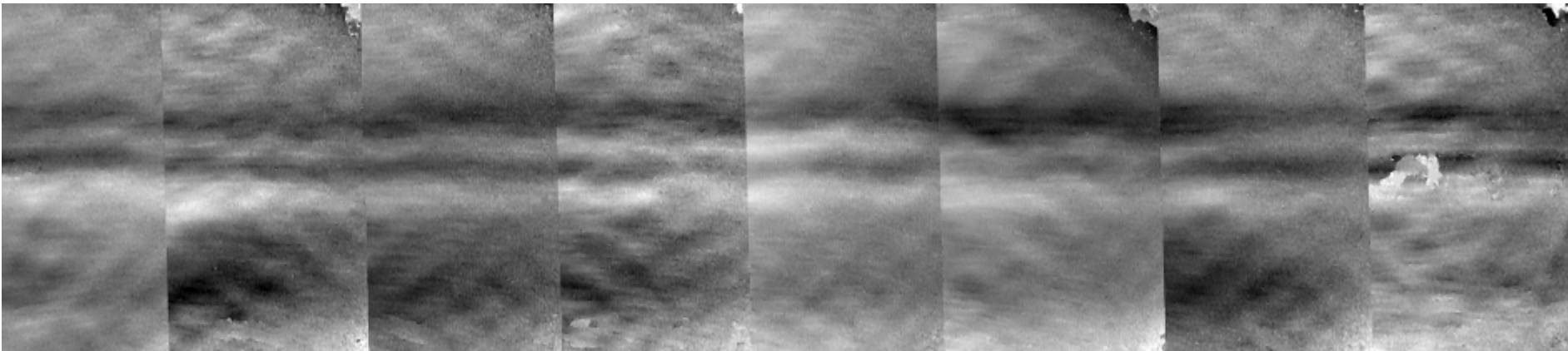
s/n 012

Band 2 Equator over Circumferential Weld

**Results:  
No Anomaly  
Indications  
Detected**

0°

360°

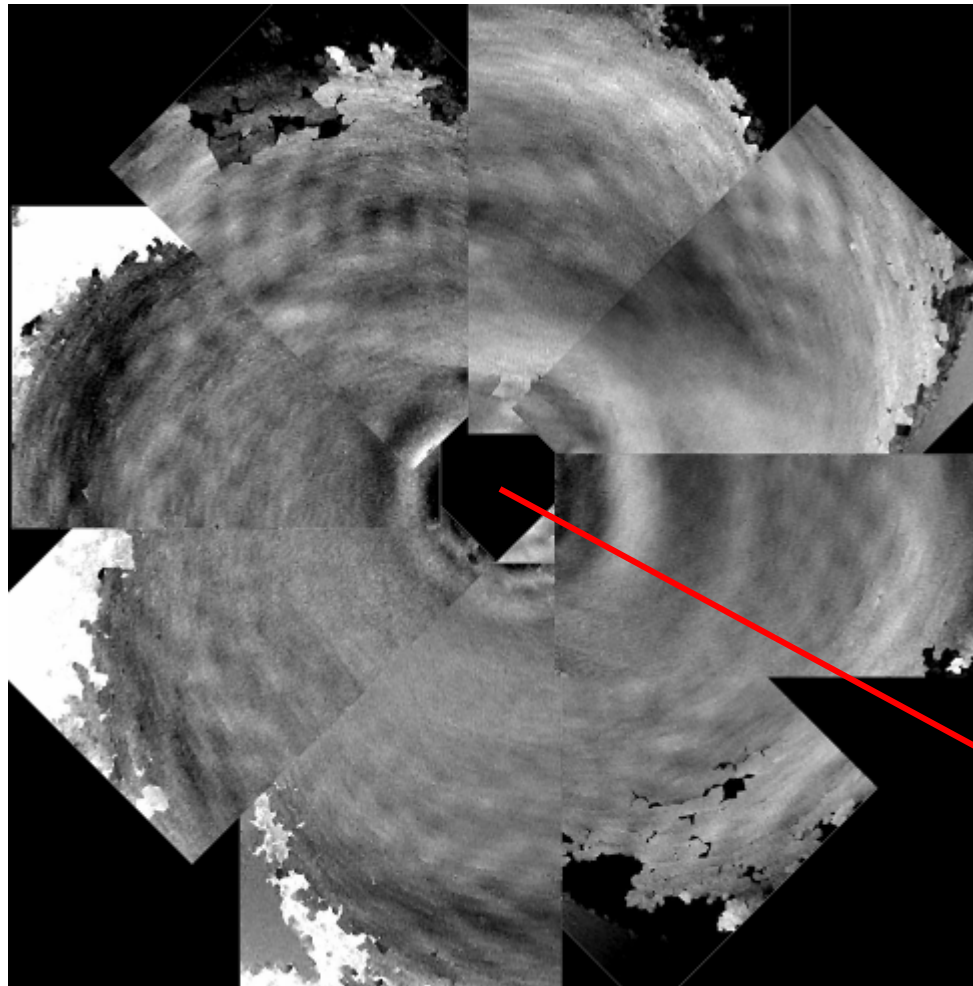


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 012

## Band 3 Blank Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°



# **Shearography COPV Test Data**

**10 1/4 Inch Kevlar  
Sphere s/n 014**

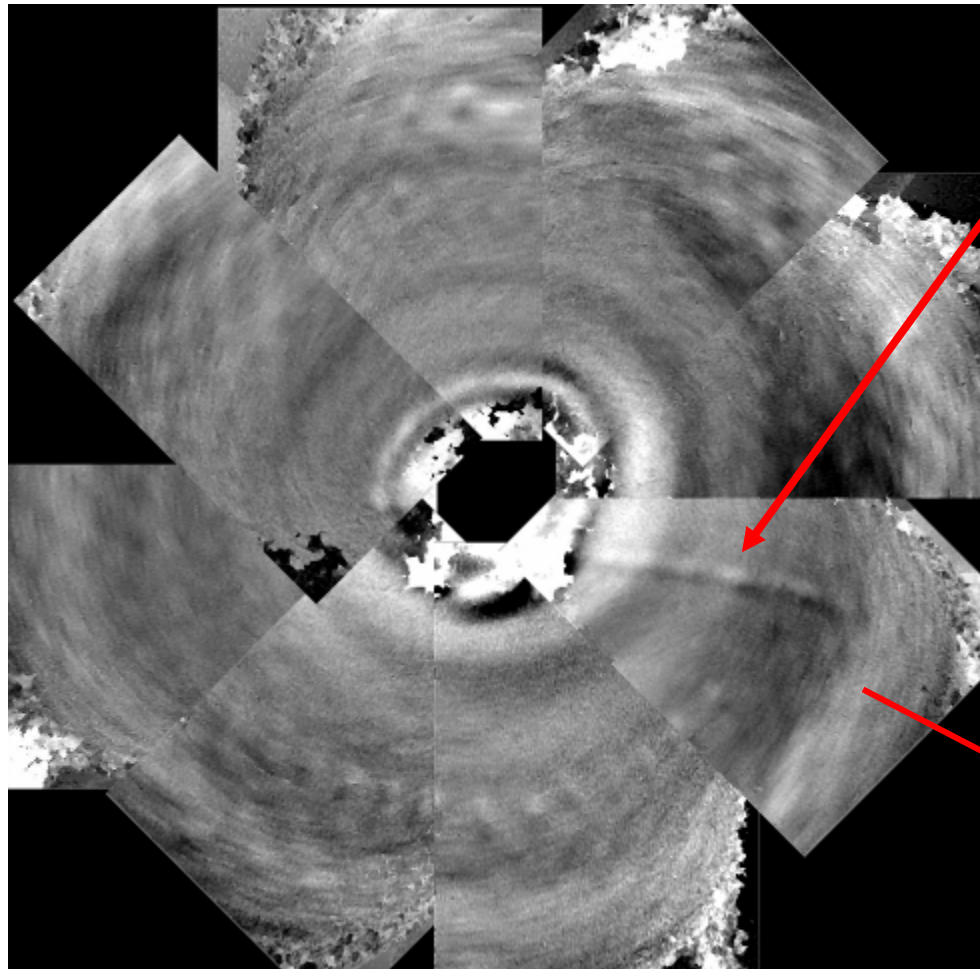


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 014

## Band 1 Pressure Port End



Normal Stress  
Concentration  
Due to Closure  
Pattern at Boss

**Results:  
No Anomaly  
Indications  
Detected**

0°

# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

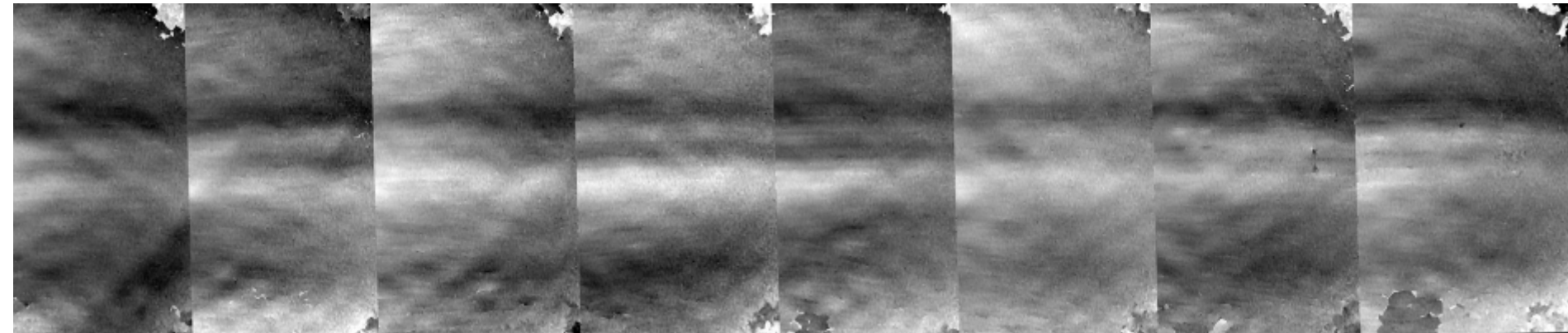
s/n 014

Band 2 Equator over Circumferential Weld

**Results:  
No Anomaly  
Indications  
Detected**

0°

360°

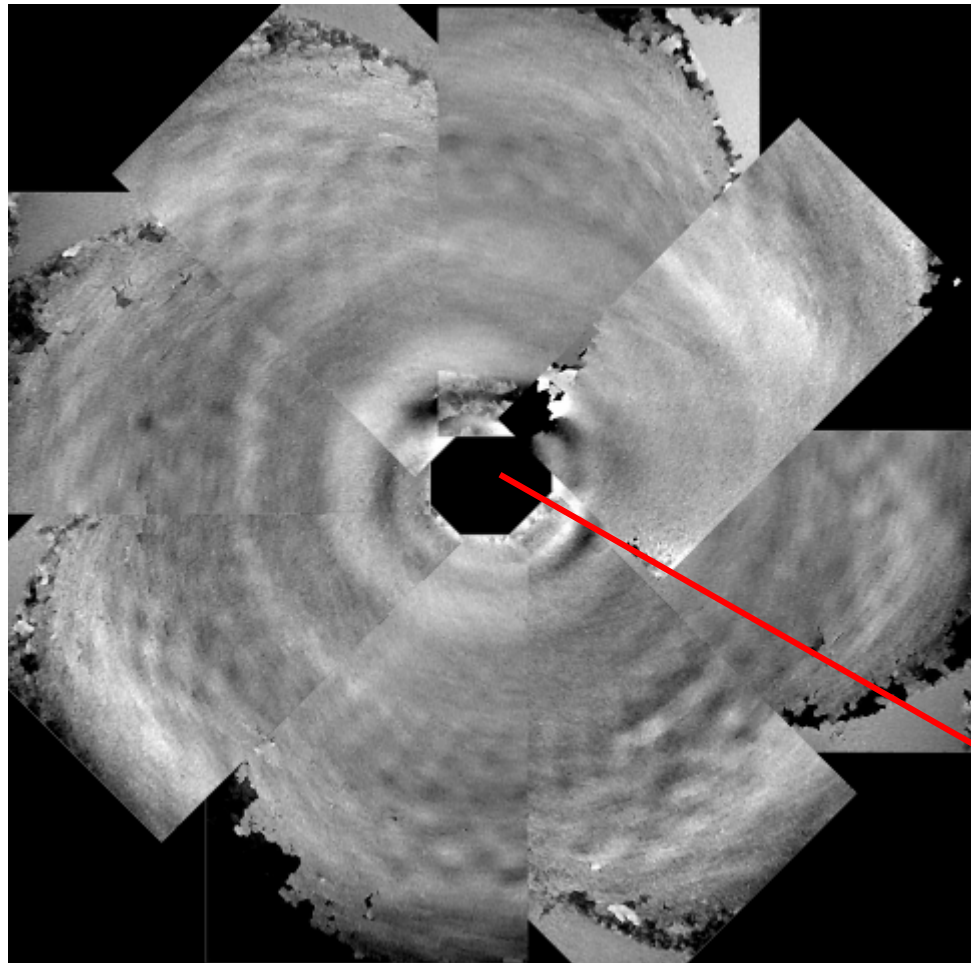


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 014

## Band 3 Blank Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# **Shearography COPV Test Data**

**10 1/4 Inch Kevlar  
Sphere s/n 015**



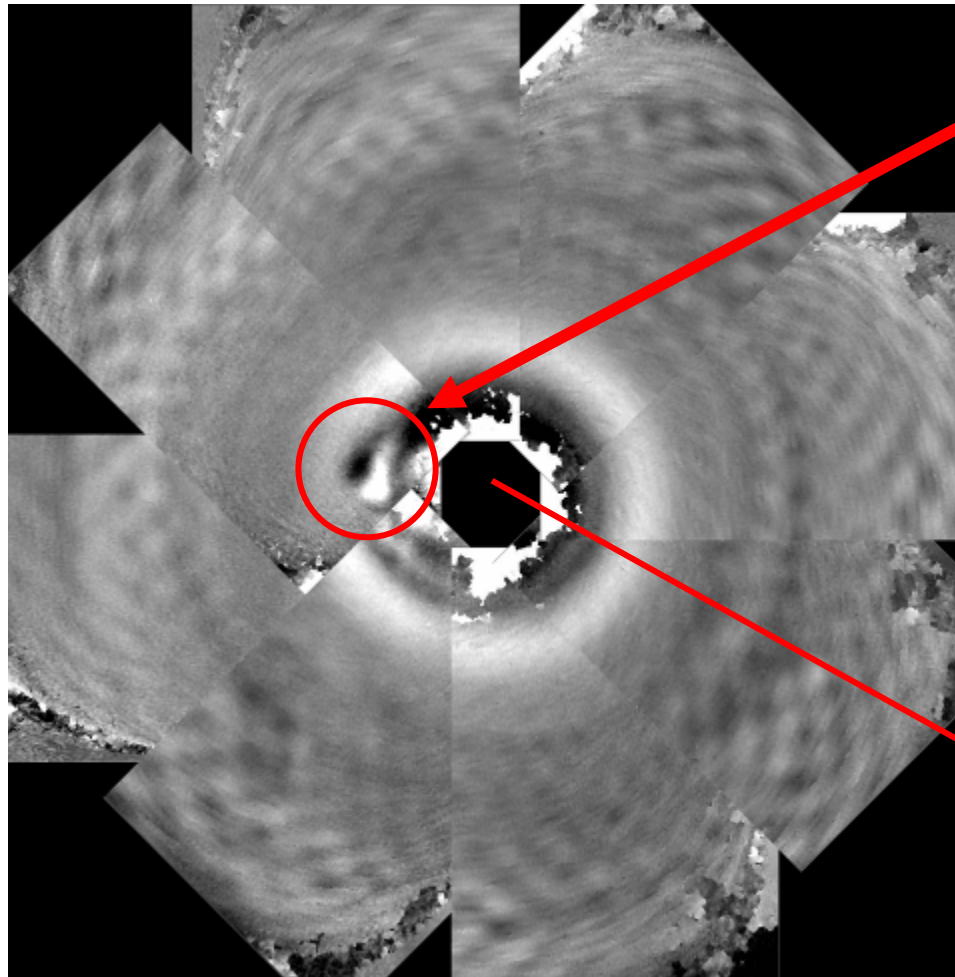


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 015

## Band 1 Pressure Port End



**Results:  
Anomaly  
Indications  
Detected.  
Unusually  
High Stress  
Concentration  
At Pressure  
Port Boss**

0°

# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

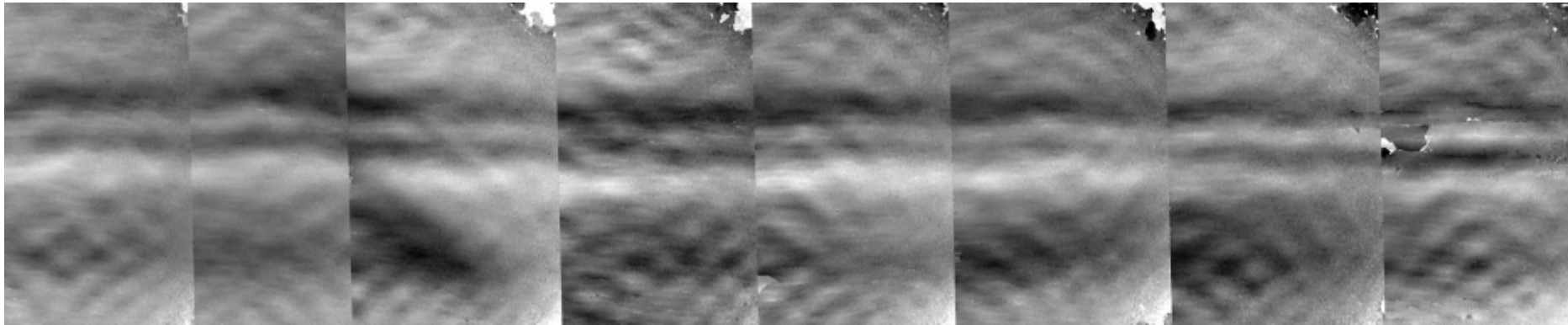
s/n 015

Band 2 Equator over Circumferential Weld

**Results:  
No Anomaly  
Indications  
Detected**

0°

360°

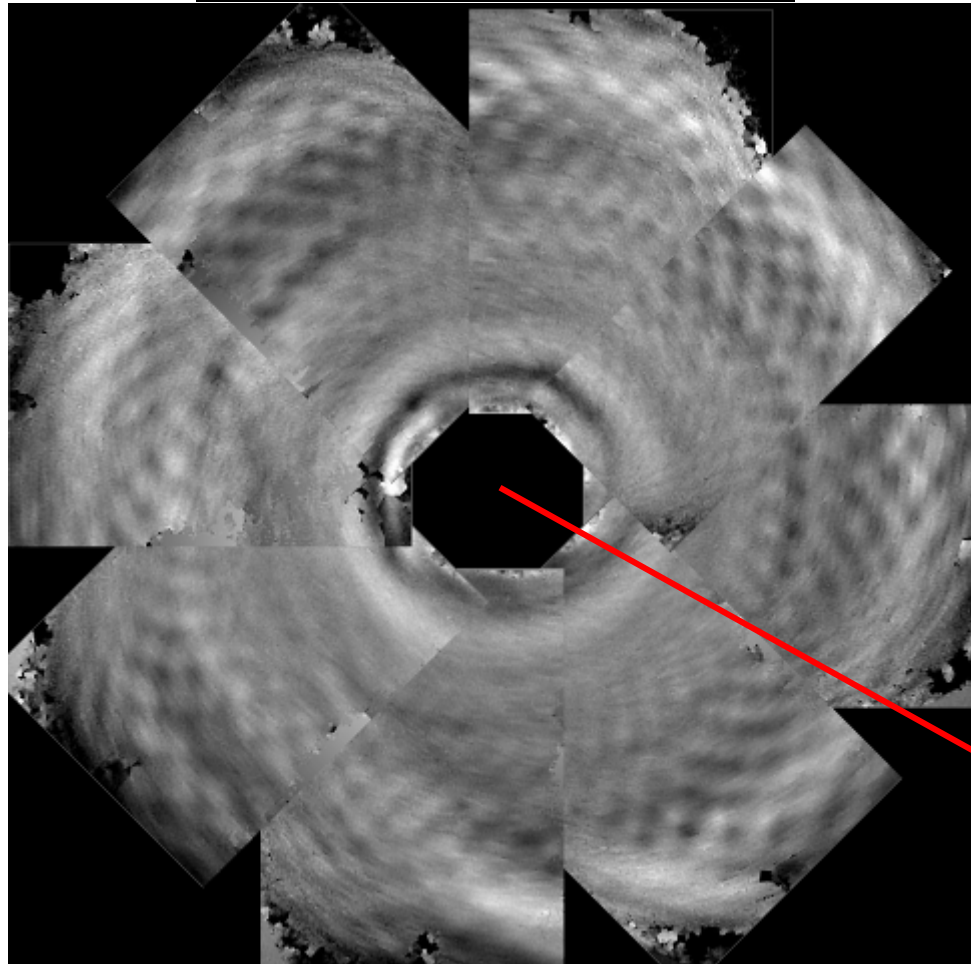


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 015

## Band 3 Blank Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°



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# **Shearography COPV Test Data**

**10 1/4 Inch Kevlar  
Sphere s/n 019**

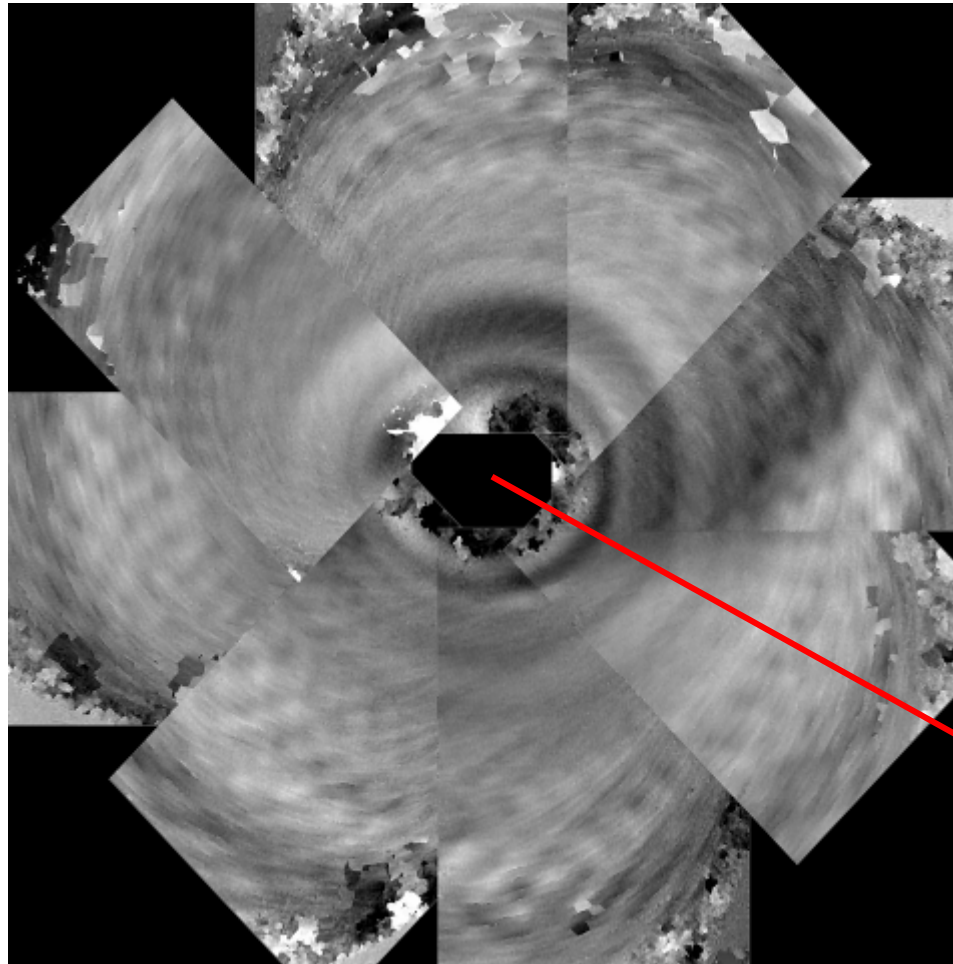


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 019

## Band 1 Pressure Port End



**Results:  
No Anomaly  
Indications  
Detected**

0°



# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

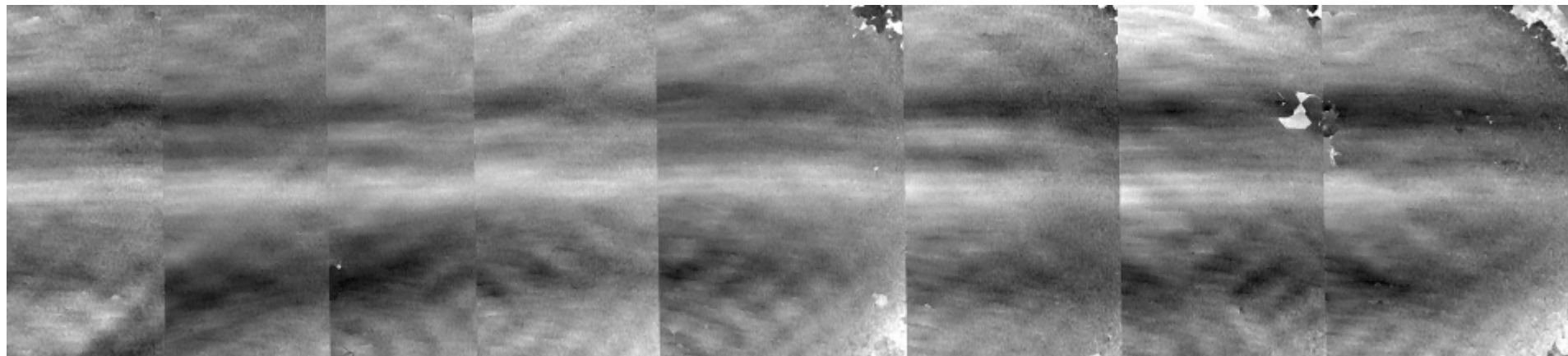
s/n 019

Band 2 Equator over Circumferential Weld

**Results:  
No Anomaly  
Indications  
Detected**

0°

360°

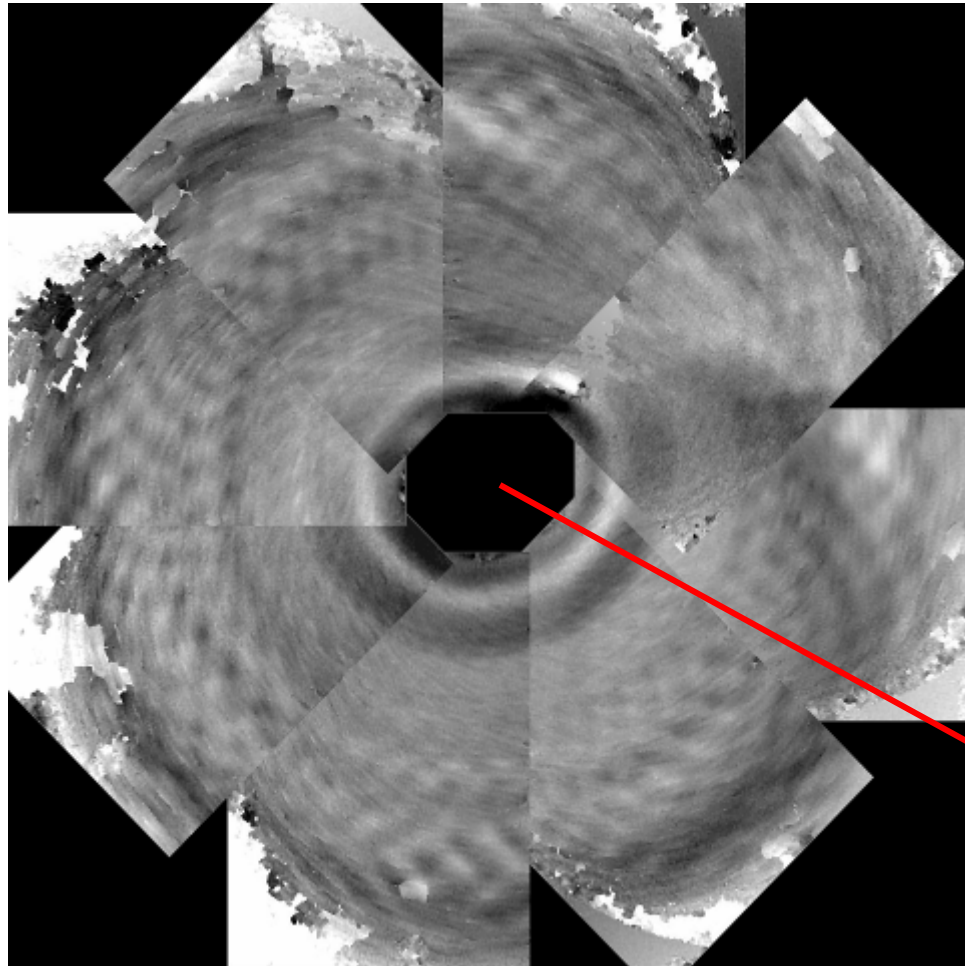


# Shearography COPV Test Data

10 1/4 Inch Kevlar Sphere

s/n 019

## Band 3 Blank Boss End



**Results:  
No Anomaly  
Indications  
Detected**

0°

# **Graphite COPV Shearography Test Results**

## **Space Station Graphite COPV**

- Cylinder 6 x 22 inch s/n 010
- Cylinder 6 x 22 inch s/n 015
- Cylinder 6 x 22 inch s/n 026
- Cylinder 6 x 22 inch s/n 027
- Cylinder 6 x 22 inch s/n 063
- Cylinder 6 x 22 inch s/n 139
- Cylinder 13 x 25 inch s/n 021
- Sphere 10.25 inch s/n 060
- Sphere 10.25 inch s/n 066
- Sphere 10.25 inch s/n 074
- Sphere 18 inch s/n 010

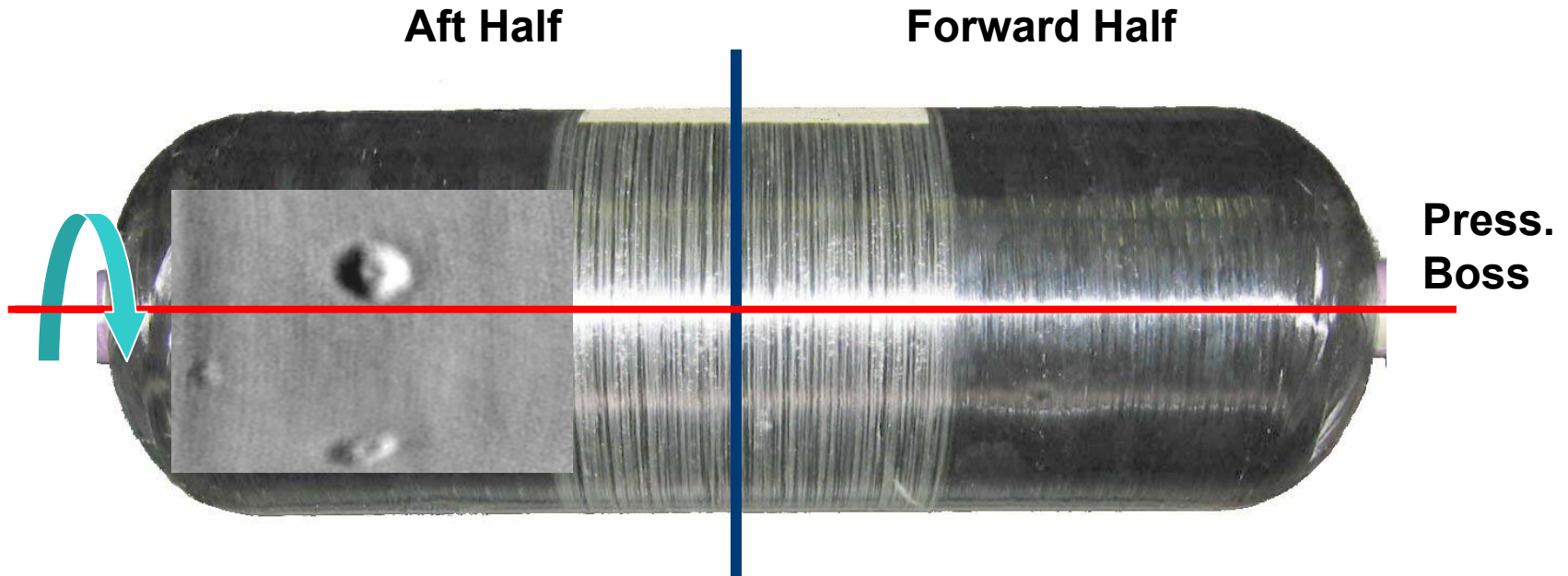


# **Shearography COPV Test Data**

## **6 x 22 Inch Graphite Cylinders**



# Shearography Scan Plan 6 x 22 Inch Graphite Cylinders



- Tank tested in 2 bands, Aft Half and Forward Half
- Tank rotated one frame after each test as shown.
- Shearogram shows damage to scale on tank photo.



# Shearography COPV Test Data

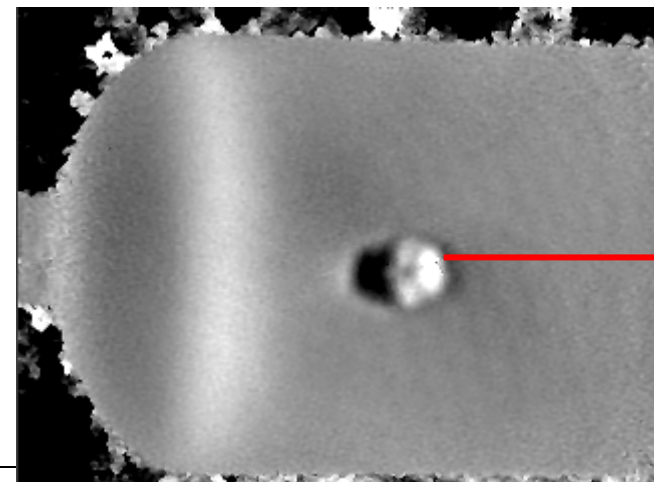
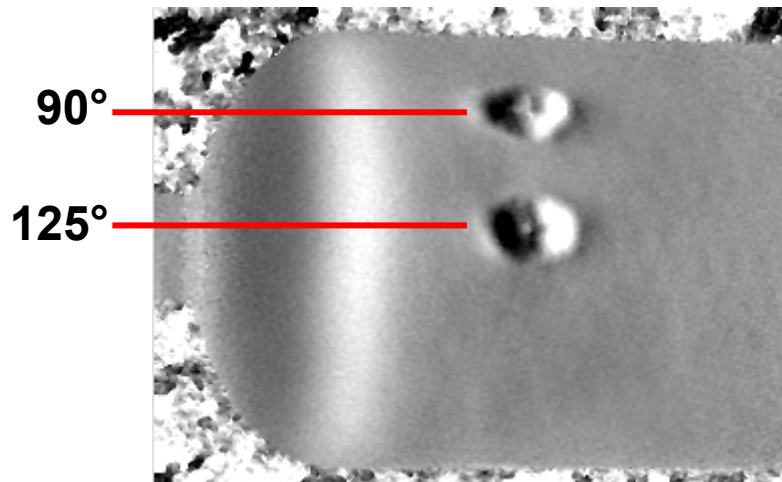
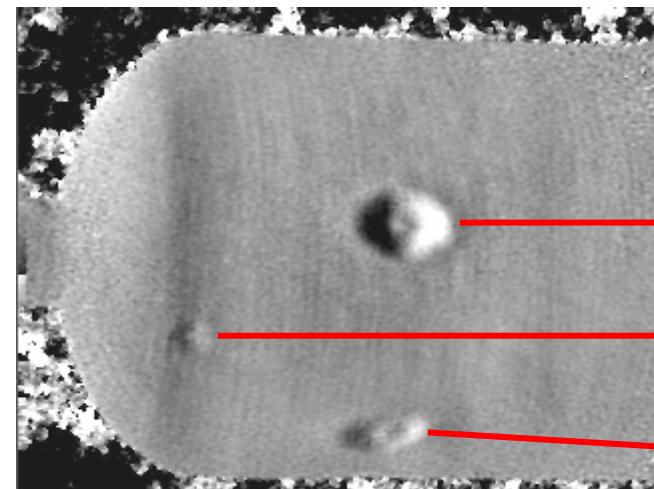
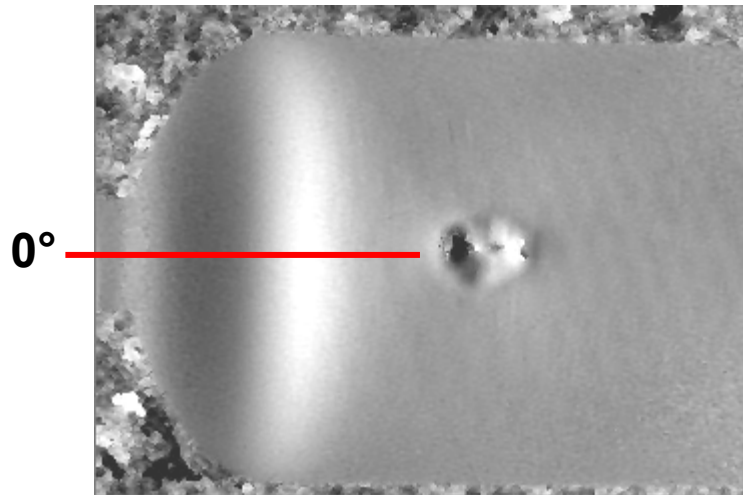
6 x 22 Inch Graphite Cylinder  
SCI s/n 010



# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

SCI s/n 010



Note: Indications at 200°, 215° are not listed on the VT Score Sheet provided.



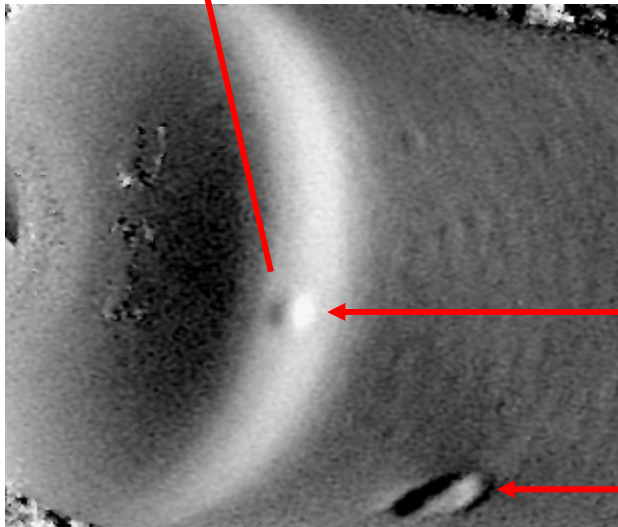
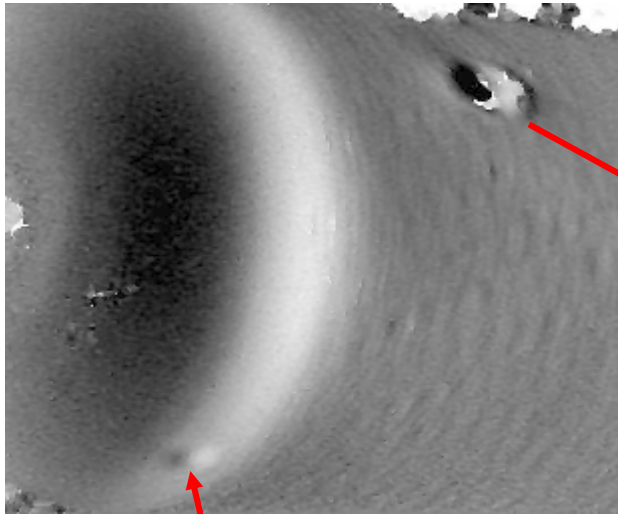
# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder  
SCI s/n 015



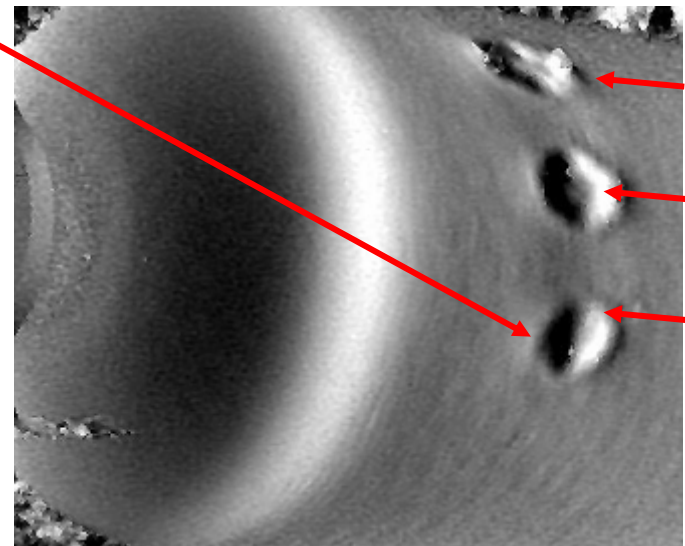
# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder SCI s/n 015



90°

45°



230°

210°

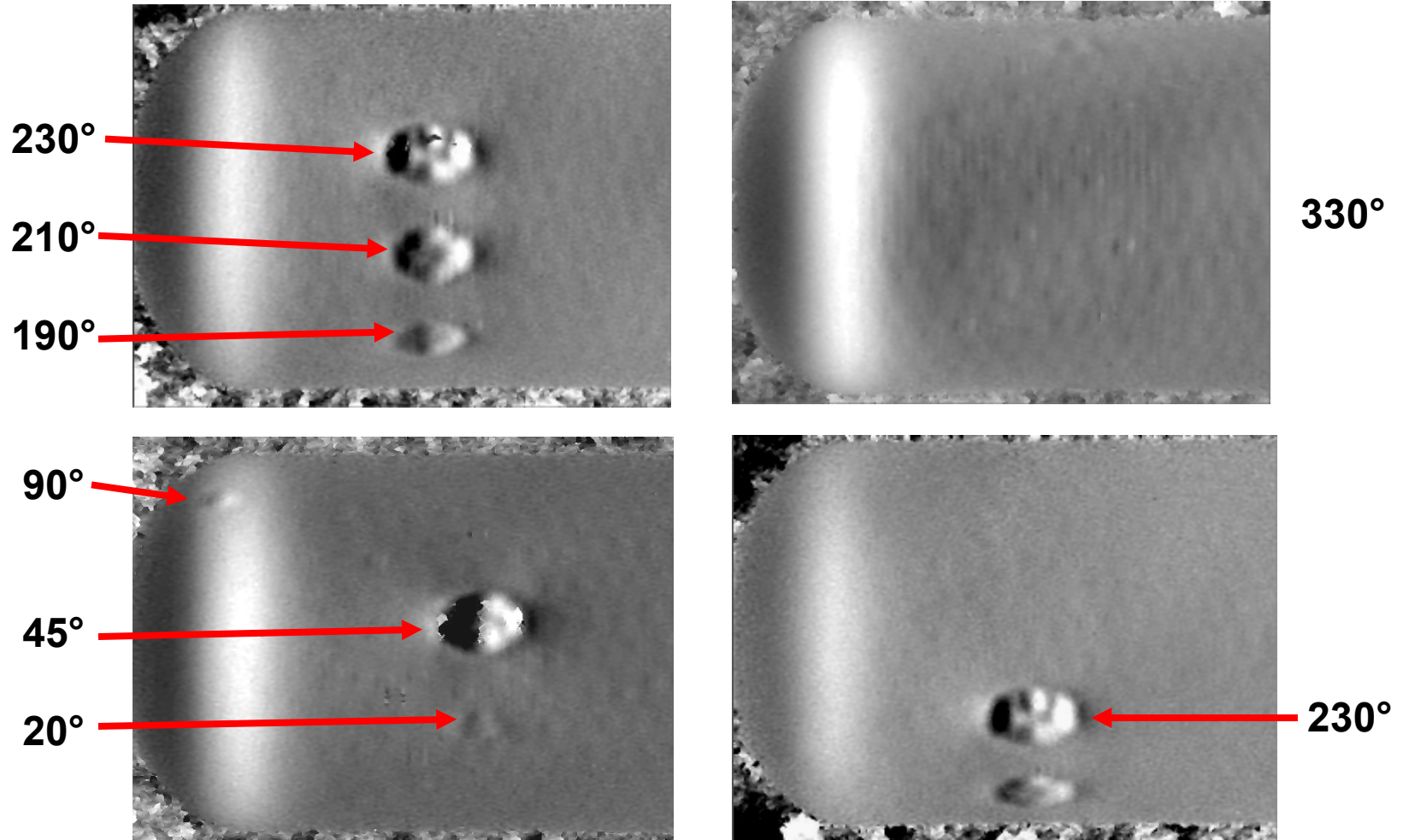
190°

## Note:

Indications at 90°, 45°, 190°, and 230° are not listed on the VT Score Sheet provided. Area at 280° not inspected.

# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder SCI s/n 015

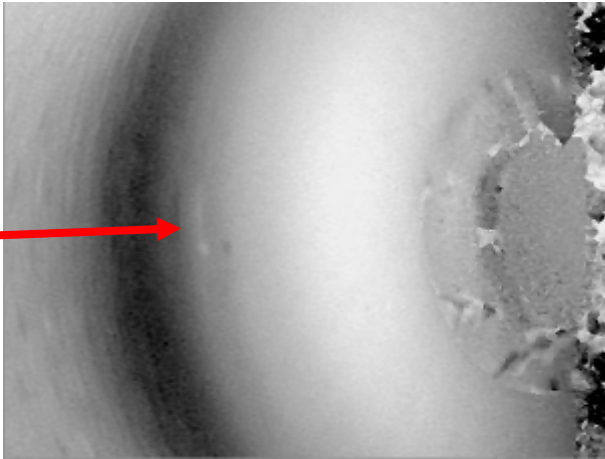




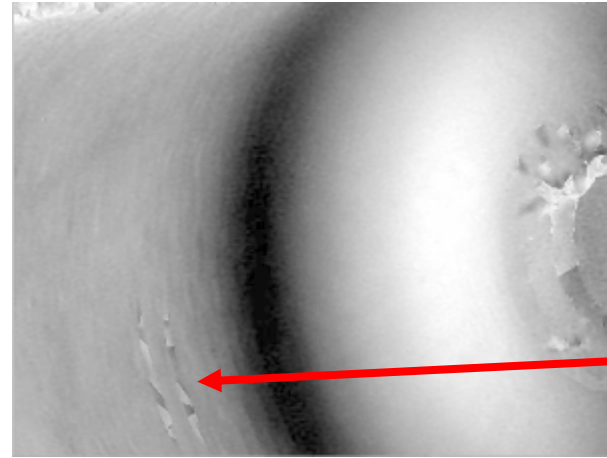
# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder SCI s/n 015

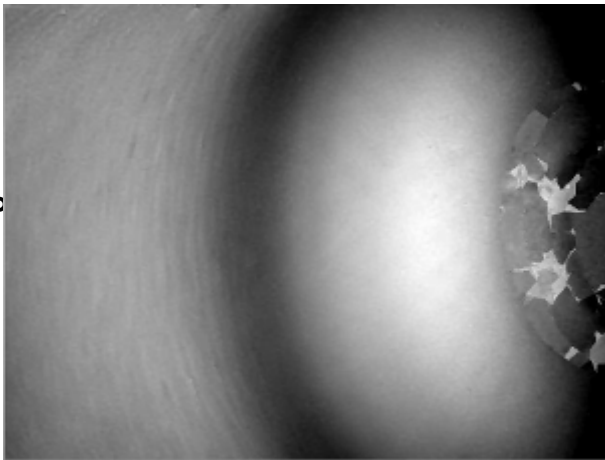
40°



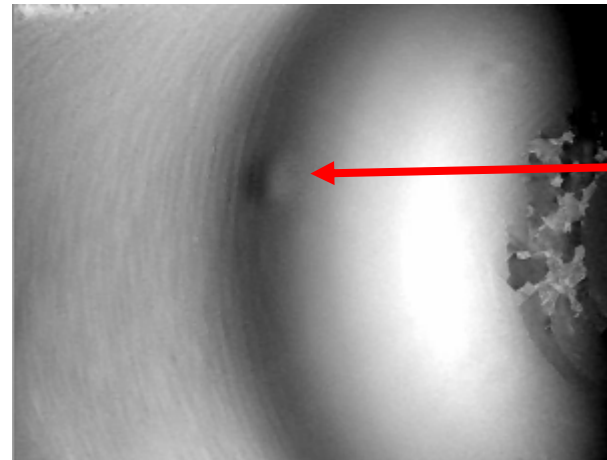
180°



135°



280°



# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder  
SCI s/n 026

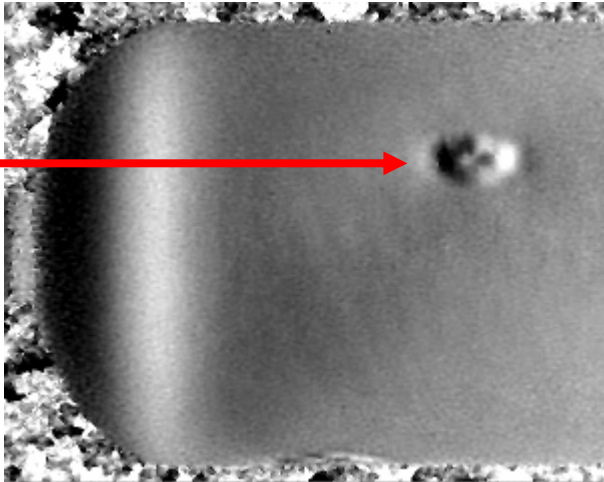


# Shearography COPV Test Data

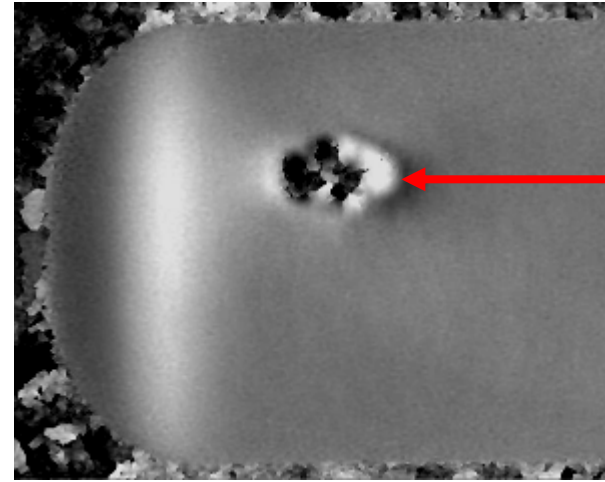
6 x 22 Inch Graphite Cylinder

s/n 026

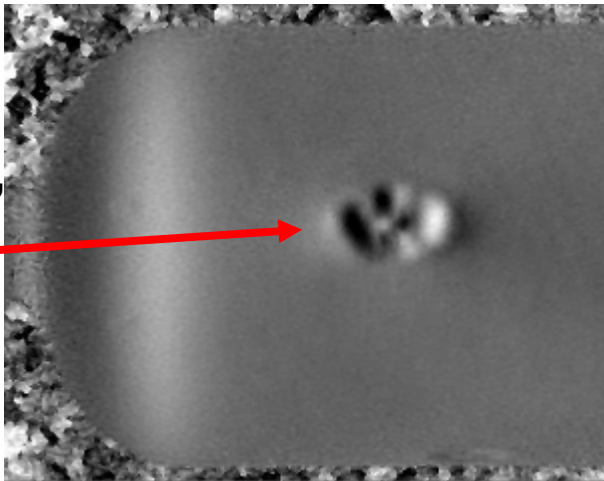
250° x 14.1°  
Damage  
.9x1.5 in.



145° x 16.0°  
Damage  
1.3 x 2.2 inch



320° x 15.25°  
Damage  
1.1 x 2.0 inch



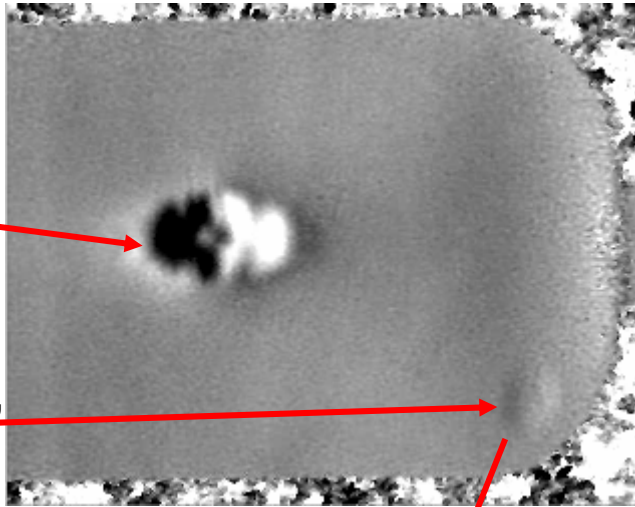
# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

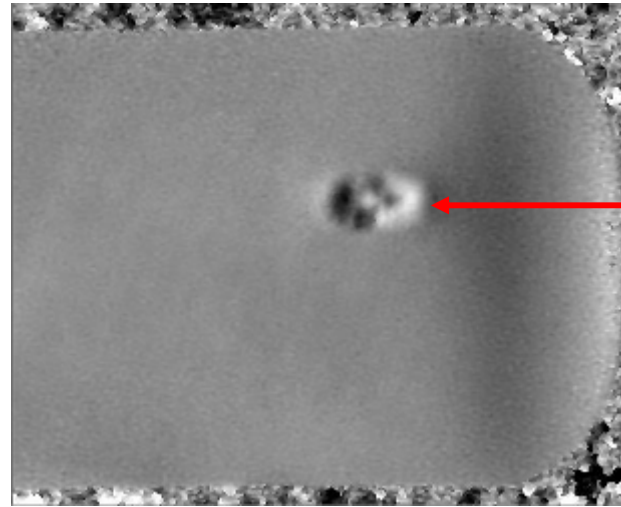
s/n 026

270° x 7"  
Damage  
1.3 x 2.2

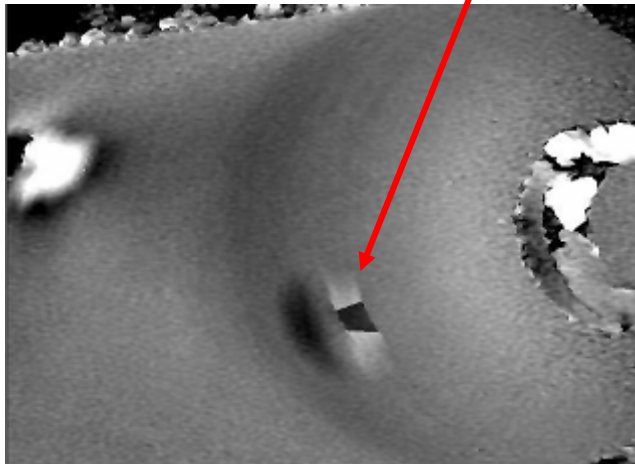
290° x 2.8"



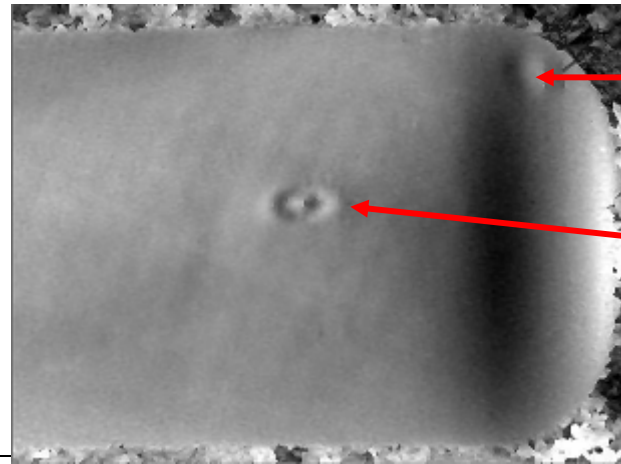
20° x 5.1 inch  
Damage .8x1.5



160° x 2.8 inch  
Damage .5x.5



180° x 6.0 inch  
Damage .5 x.9



Note: Indications at 160°, and 290° are not listed on the VT Score Card provided.



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# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder  
SCI s/n 027



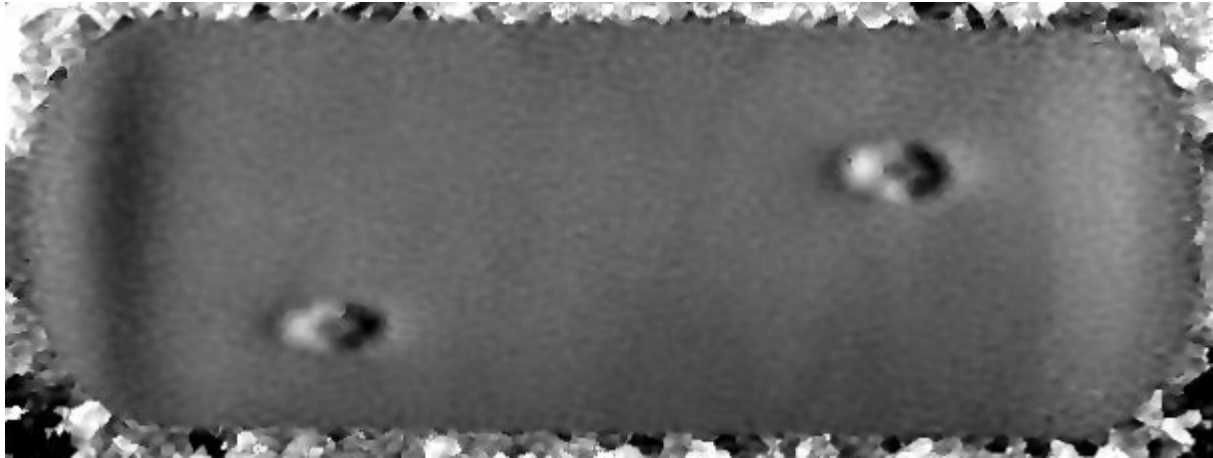


# Shearography COPV Test Data

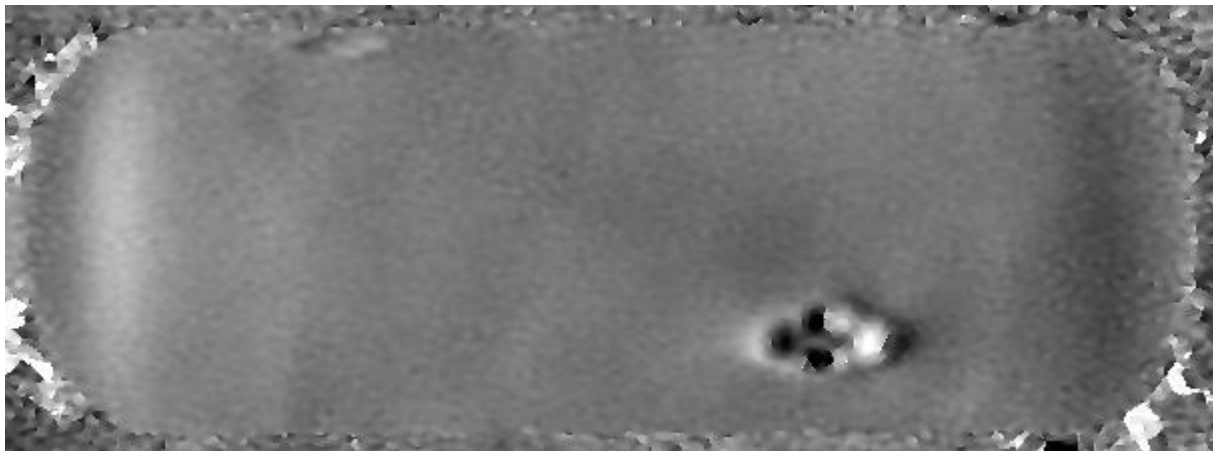
6 x 22 Inch Graphite Cylinder

s/n 027

90° to 180°



0° to 90°

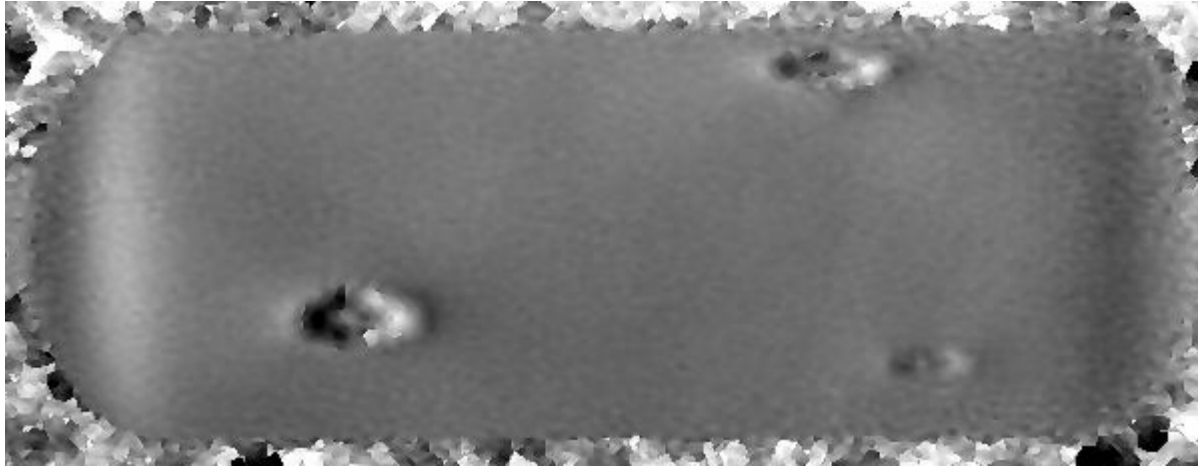


# Shearography COPV Test Data

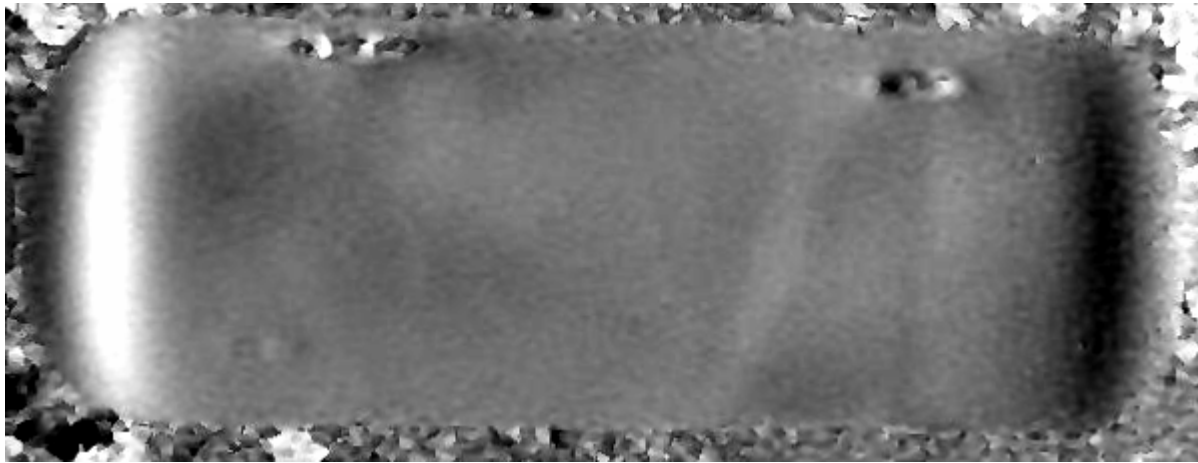
6 x 22 Inch Graphite Cylinder

s/n 027

270° to 360°



180° to 270°



# Shearography COPV Test Data

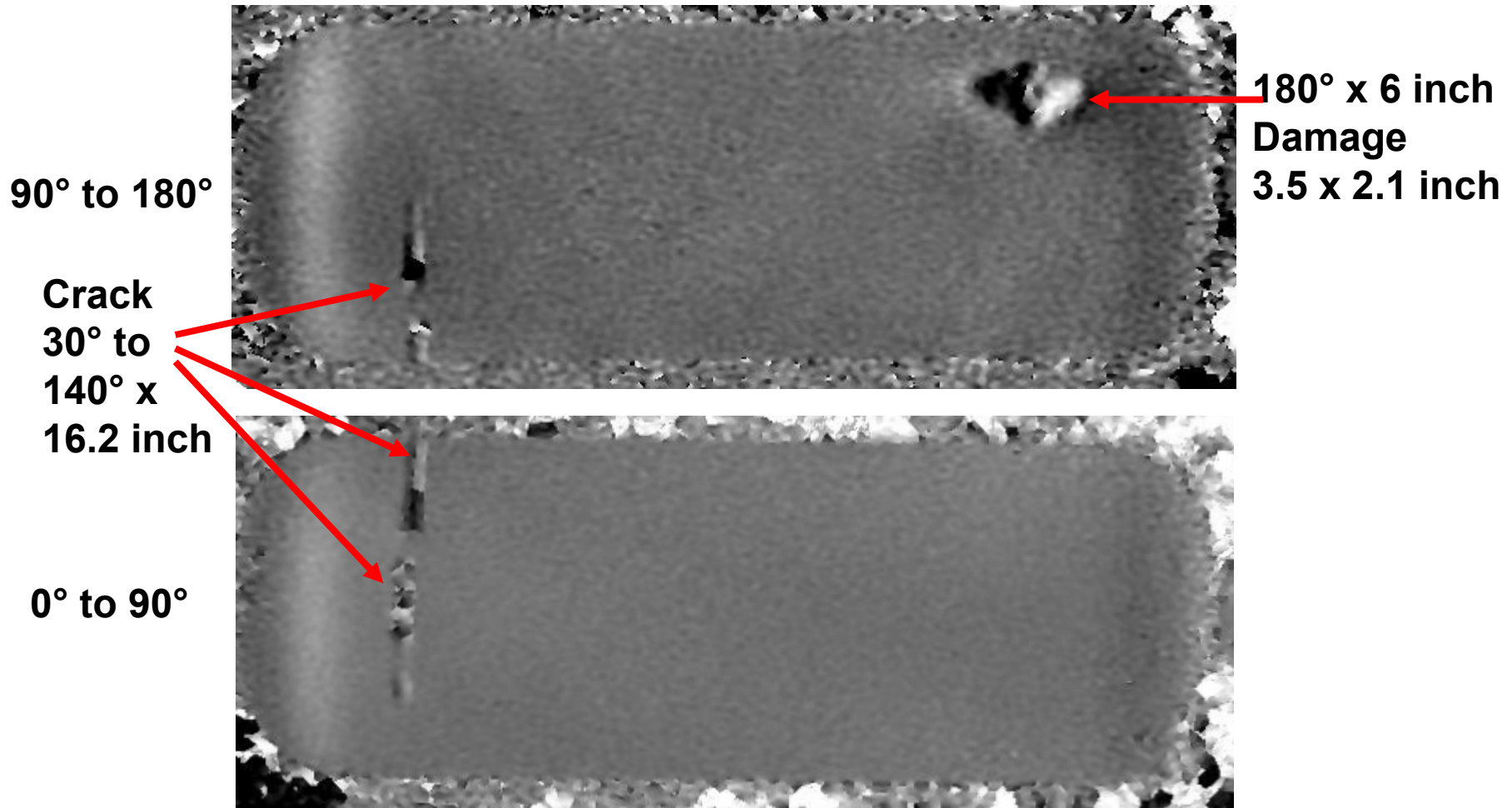
6 x 22 Inch Graphite Cylinder  
SCI s/n 063



# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

s/n 063

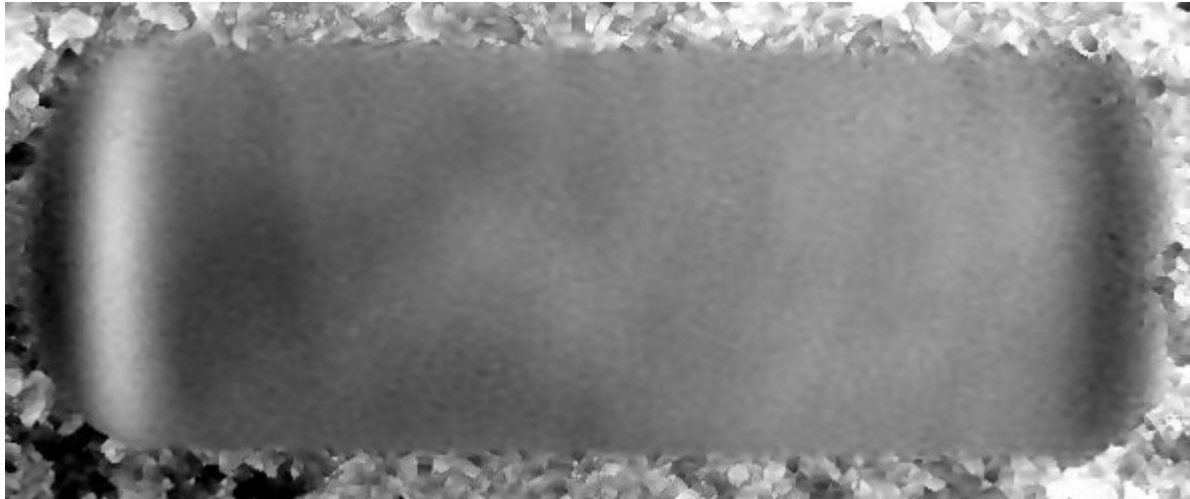


# Shearography COPV Test Data

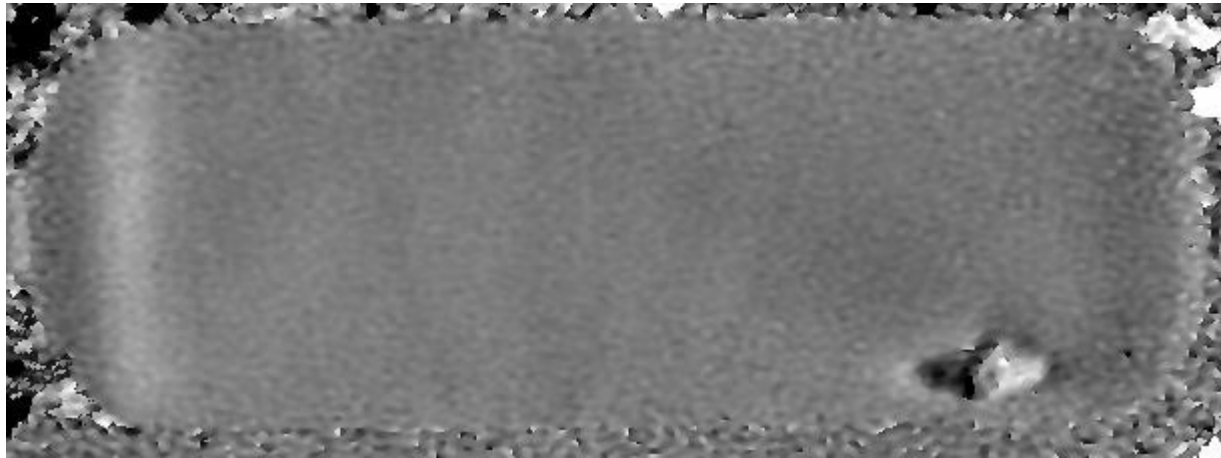
6 x 22 Inch Graphite Cylinder

s/n 063

270° to 360°



180° to 270°



# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder  
SCI s/n 139

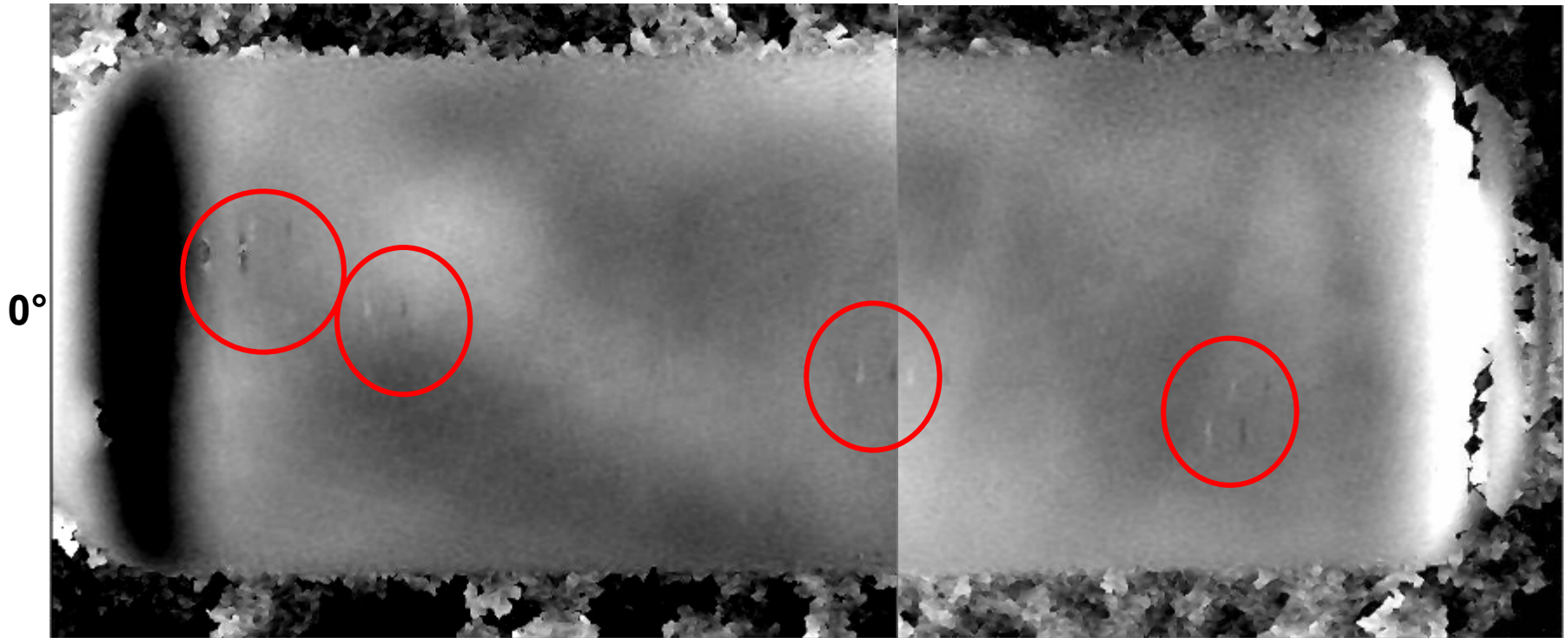




# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

s/n 139

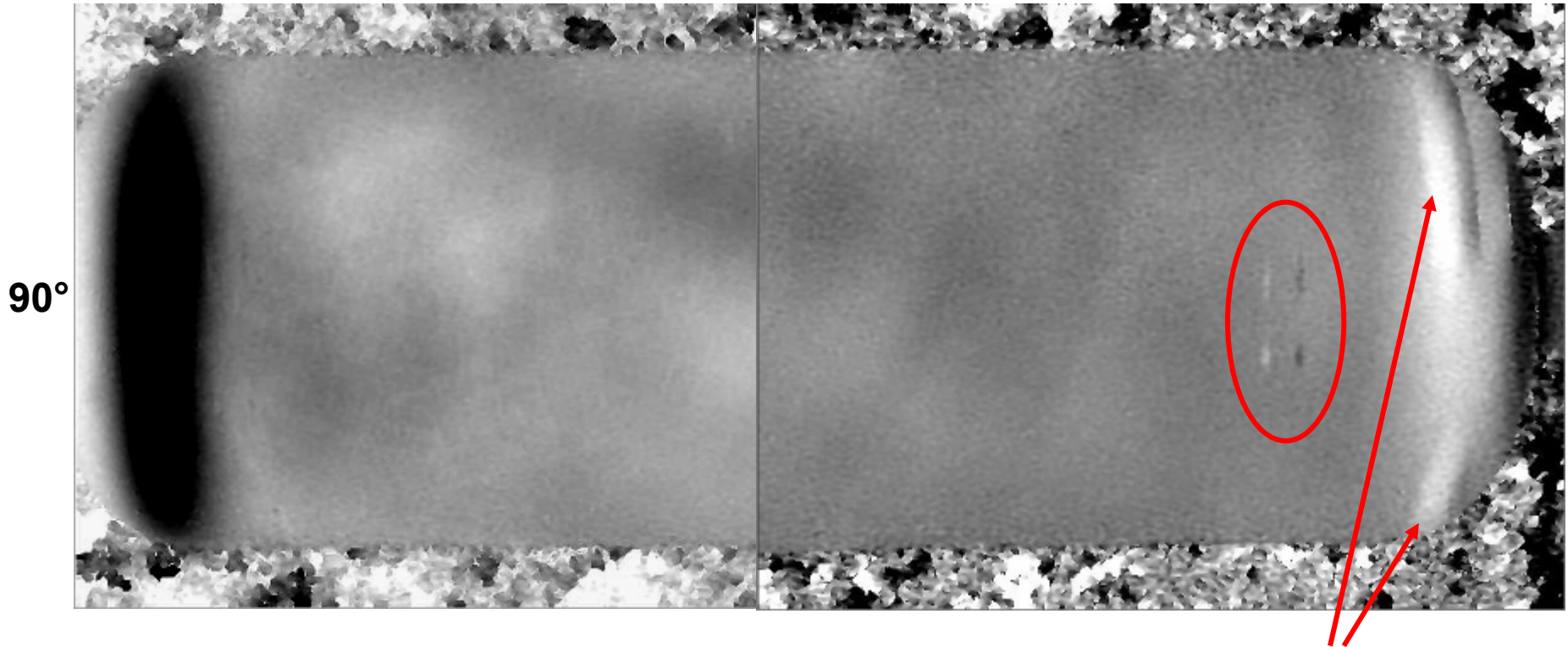


Circled areas are small cracks due to impact.

# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

s/n 139

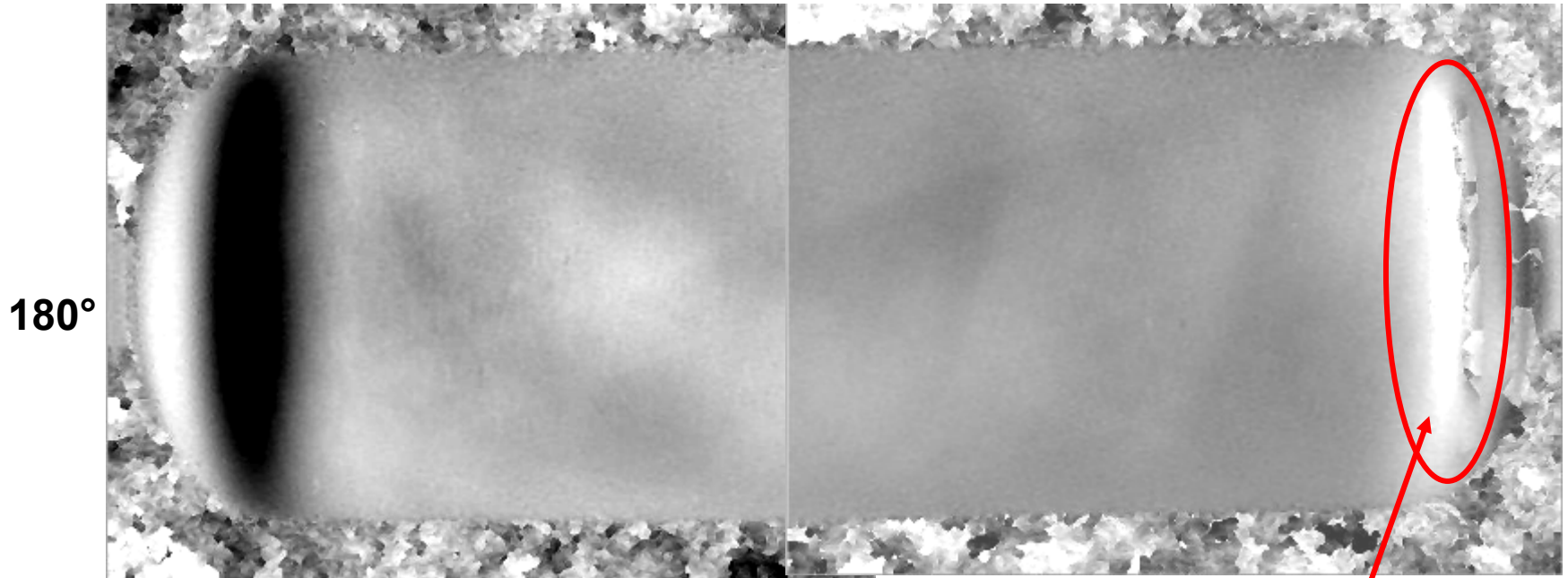


**Bridging Delaminations  
at base of dome end.**

# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

s/n 139

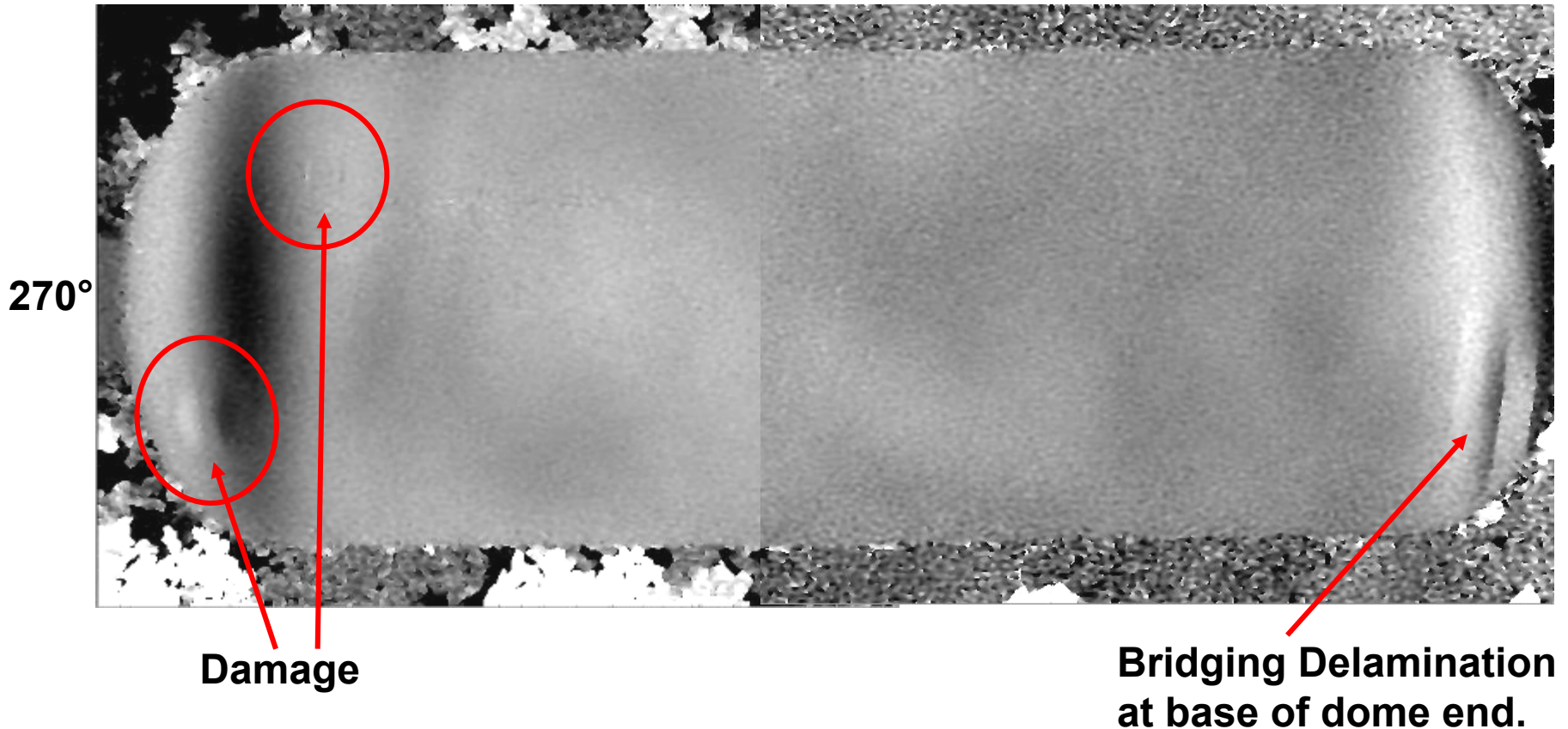


**Bridging Delamination  
at base of dome end.**

# Shearography COPV Test Data

6 x 22 Inch Graphite Cylinder

s/n 139



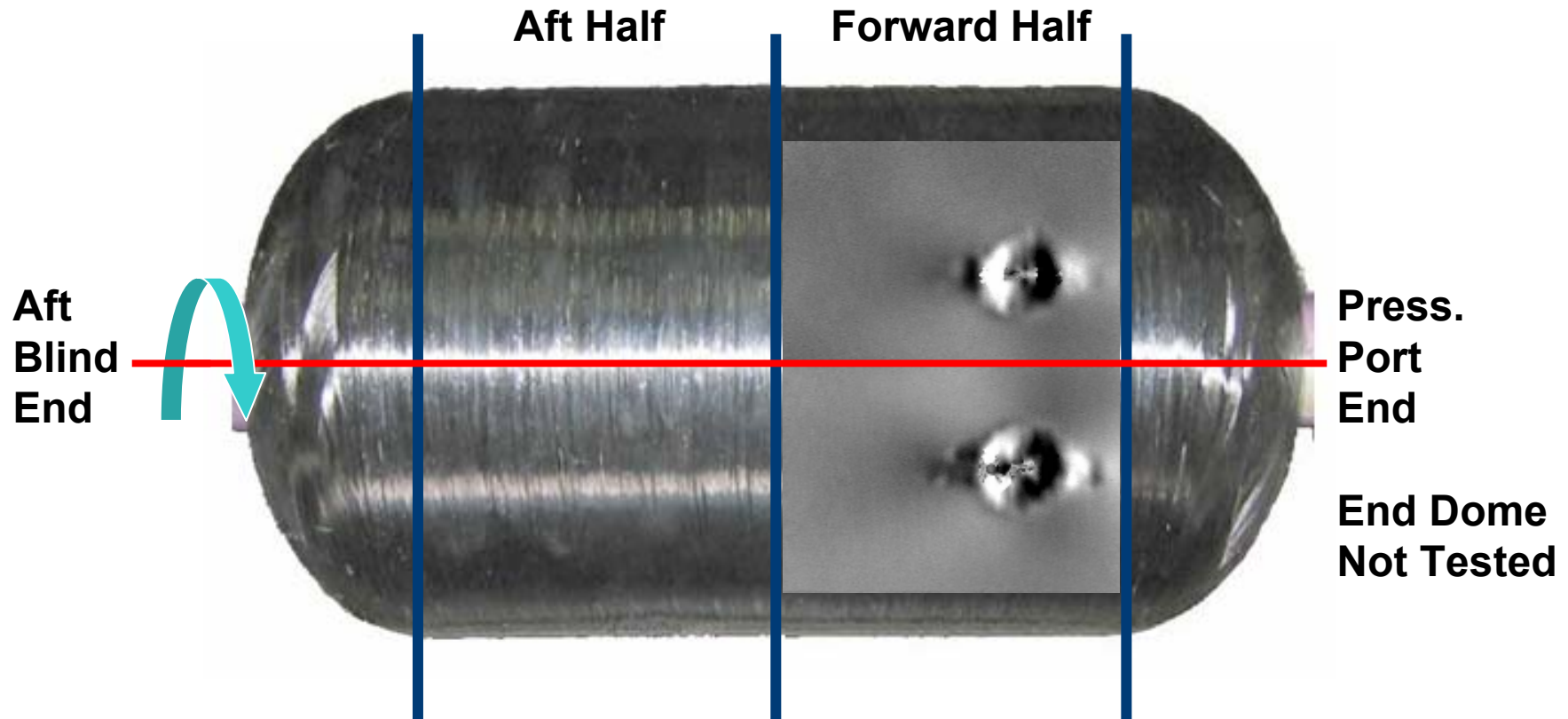
# **Shearography COPV Test Data**

## **13 x 25 Inch Graphite Cylinder**





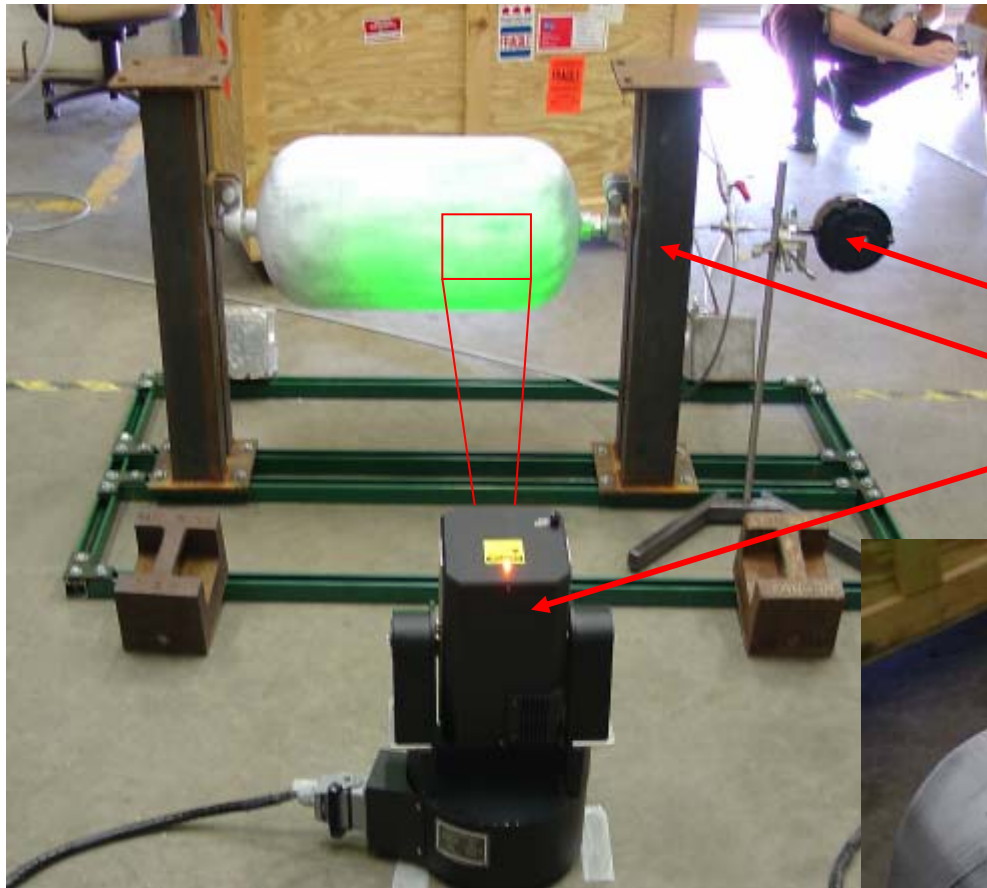
# Shearography Scan Plan 13 x 25 Inch Graphite Cylinders



- Tank tested in 2 bands, Aft Half and Forward Half
- Tank rotated one frame after each test as shown.
- Shearogram shows damage to scale on tank photo.



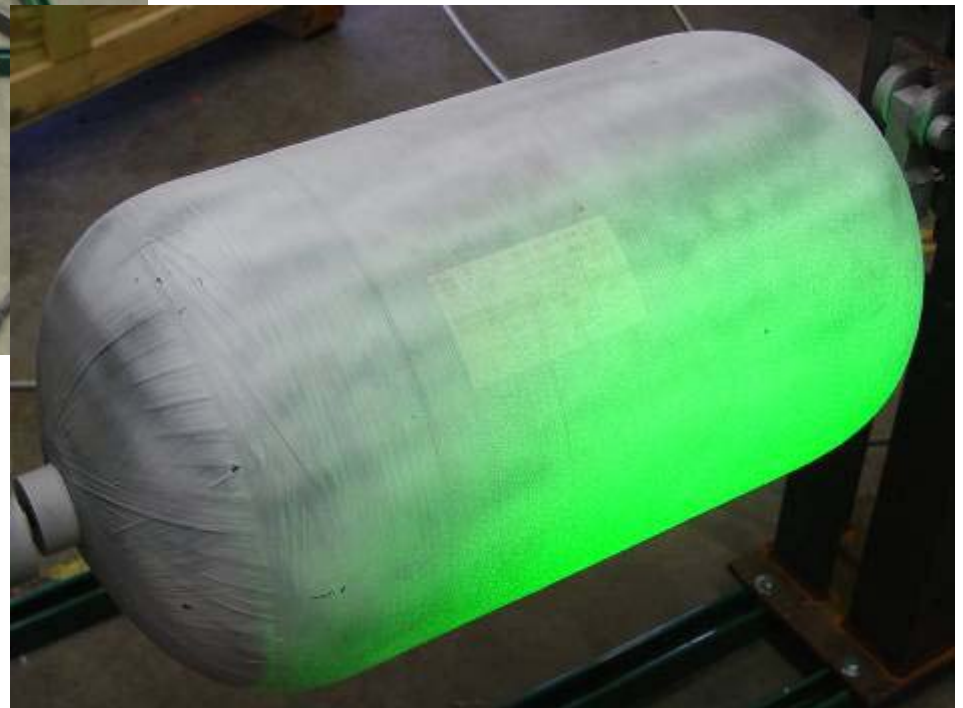
# Shearography Test Set-Up for 13 x 25 Inch Graphite COPV



Pressure Gage

Support Frame

LTI-5100 Shearography Camera



# Shearography COPV Test Data

13 x 25 Inch Graphite Cylinder  
s/n 021

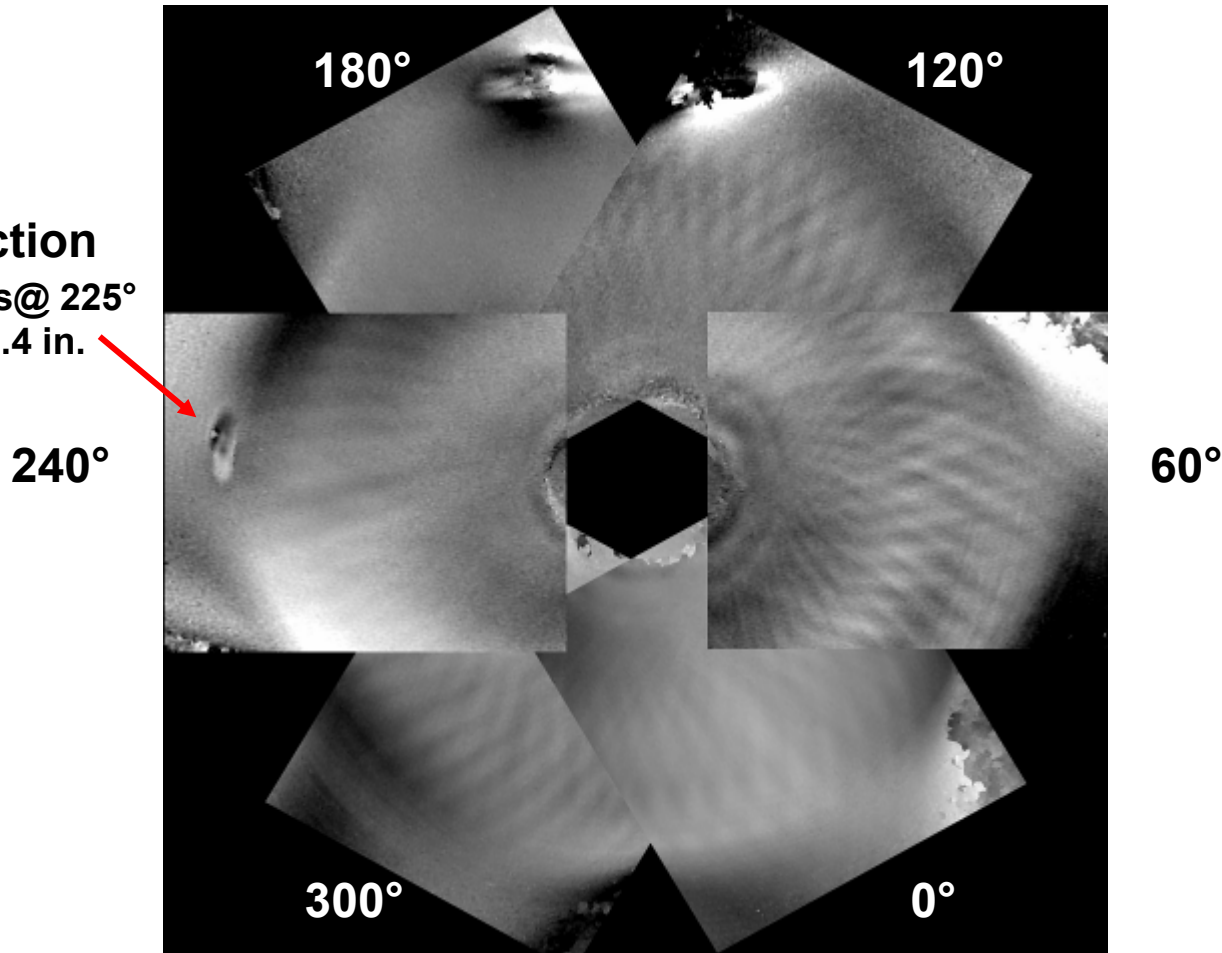


# Shearography COPV Test Data

13 x 25 Inch Graphite Cylinder s/n 021

## Aft Blind Flange End- No Defect Indication on Dome

**Impact on  
Barrel Section**  
22.1" from boss@ 225°  
Damage 1.5 x 1.4 in.

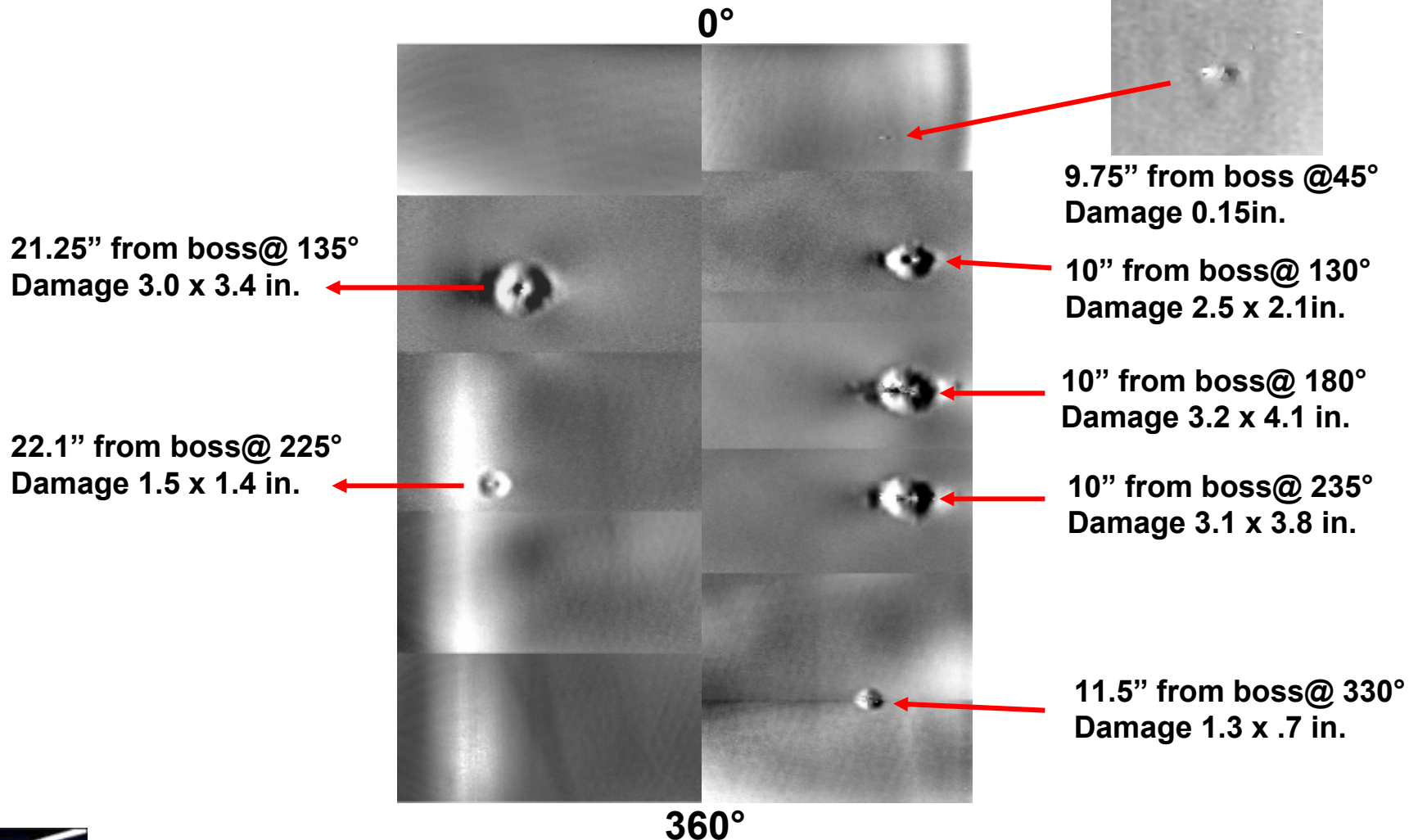


# Shearography COPV Test Data

13 x 25 Inch Graphite Cylinder

s/n 021

## Barrel Section of COPV



# **Shearography COPV Test Data**

## **10.25 Inch Graphite Spheres**





# Shearography Scan Plan 10.25 Inch Graphite Spheres

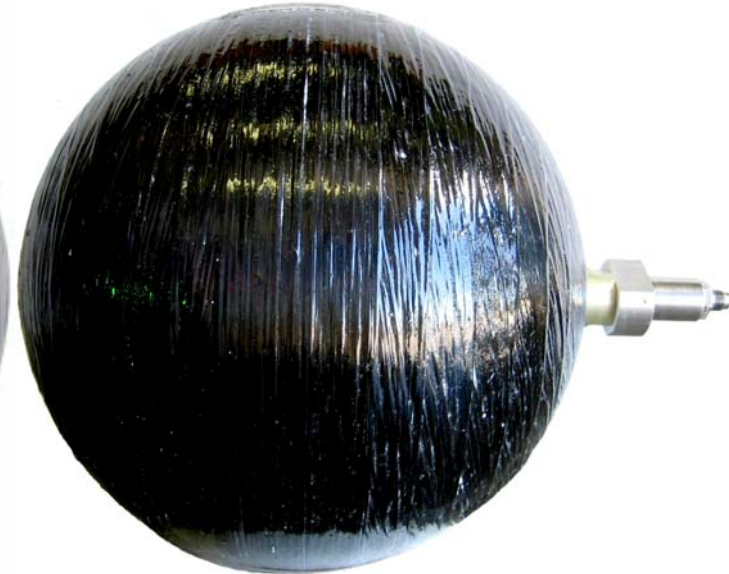
**Blind Flange View**



**Press. Flange View**



**Side View**



**Note: Due to the large number of damaged areas and limited time, images were recorded but no dimensions are provided, nor correlation with VT.**



# Shearography COPV Test Data

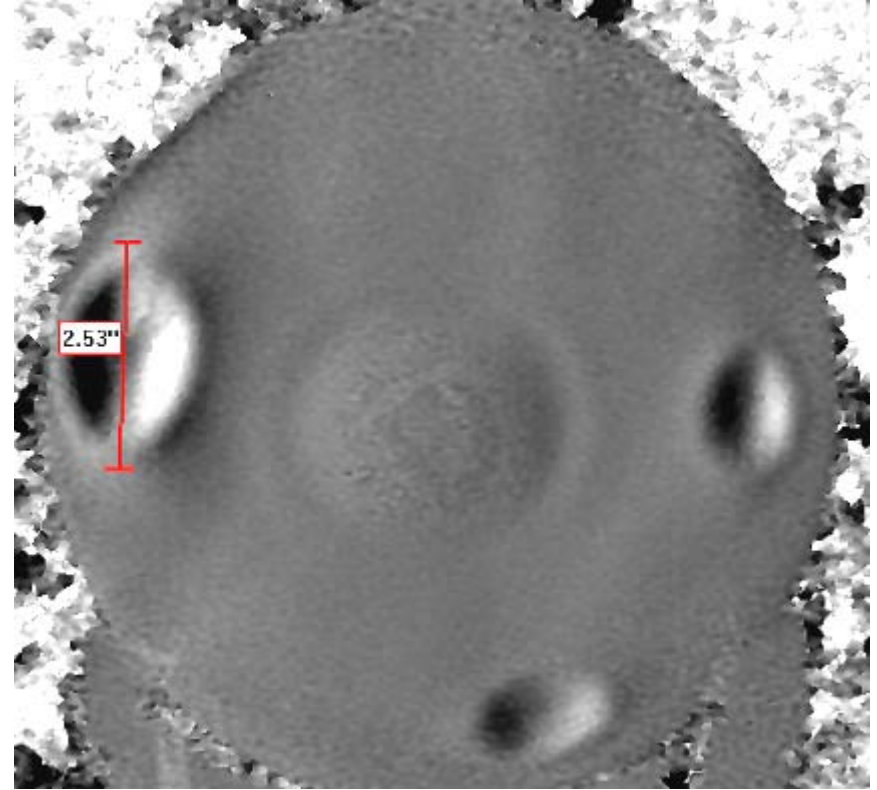
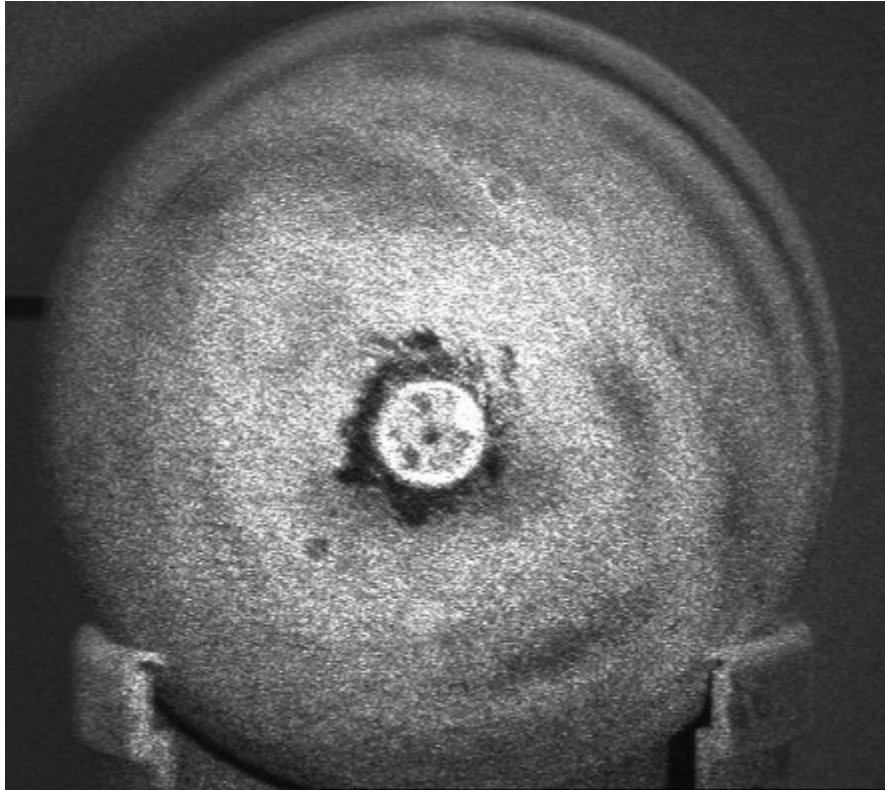
10.25 Inch Graphite Sphere  
s/n 060



# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 060

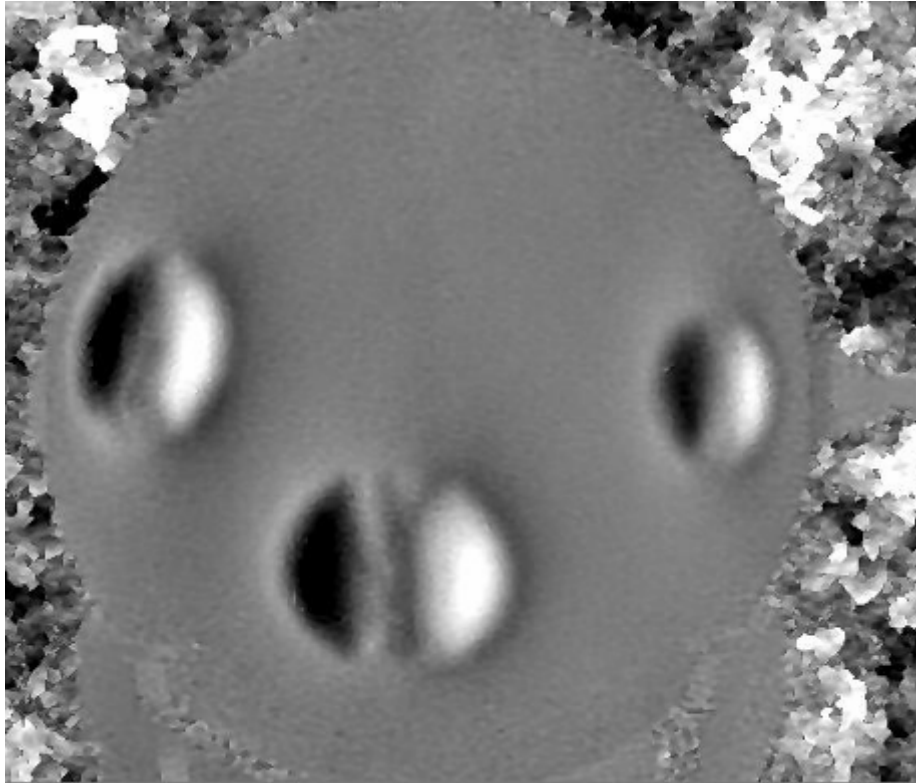
Blind Flange End



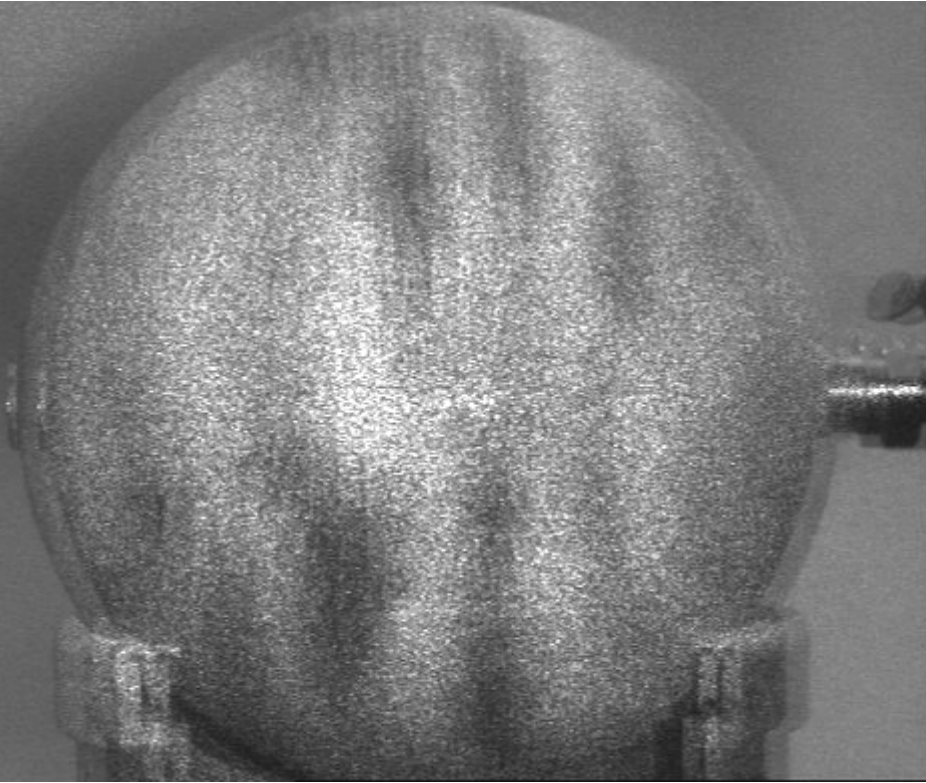
# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 060

Side View Centered on 30°



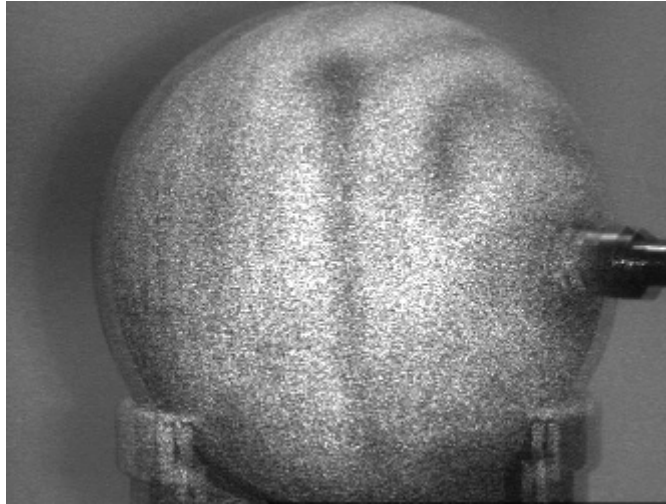
Shearography



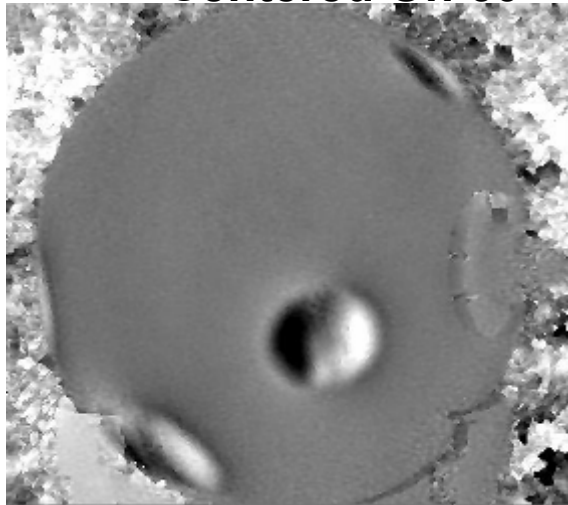
Live Image

# Shearography COPV Test Data

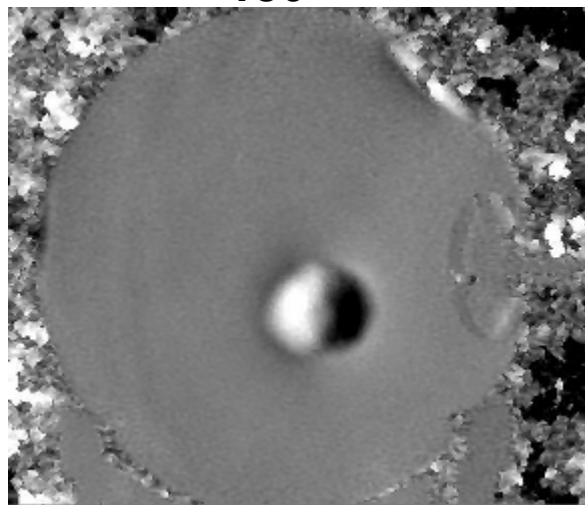
10.25 Inch Graphite Sphere s/n 060



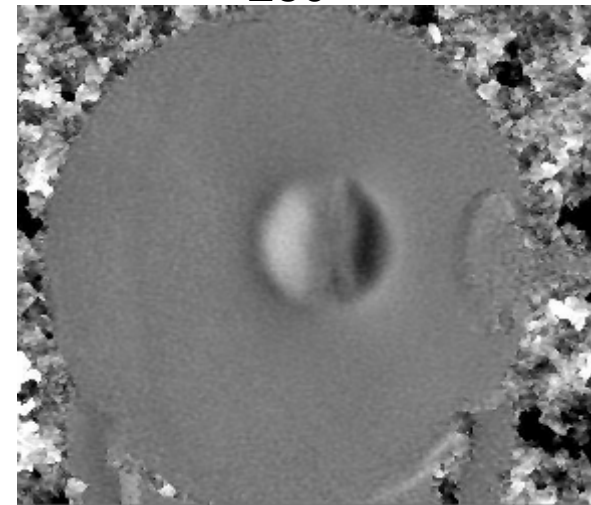
Centered On 60°



180°



280°



# Shearography COPV Test Data

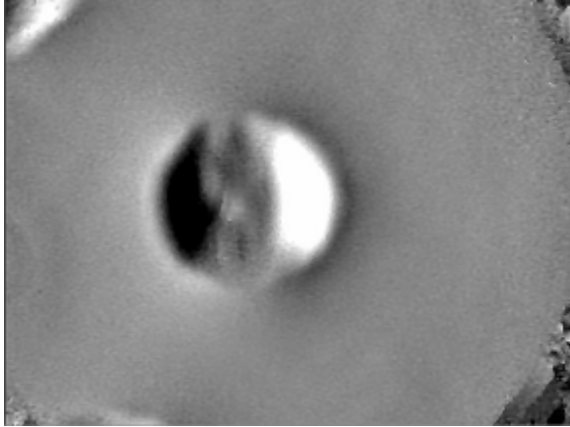
10.25 Inch Graphite Sphere  
s/n 066



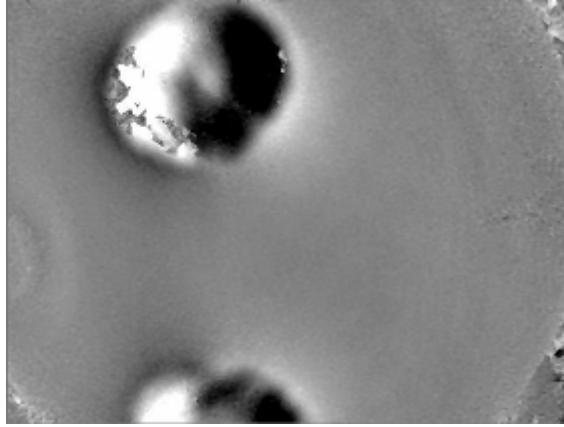


# Shearography COPV Test Data

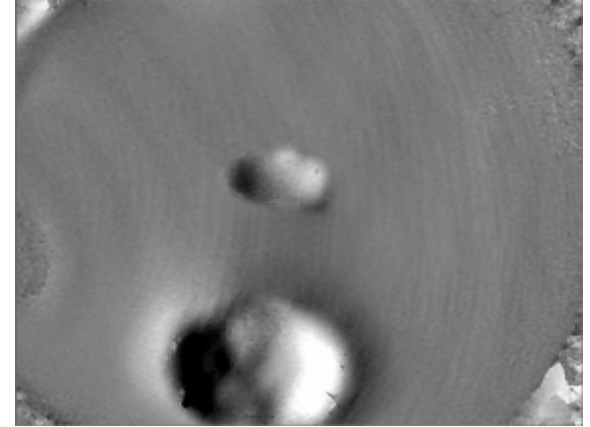
10.25 Inch Graphite Sphere s/n 066



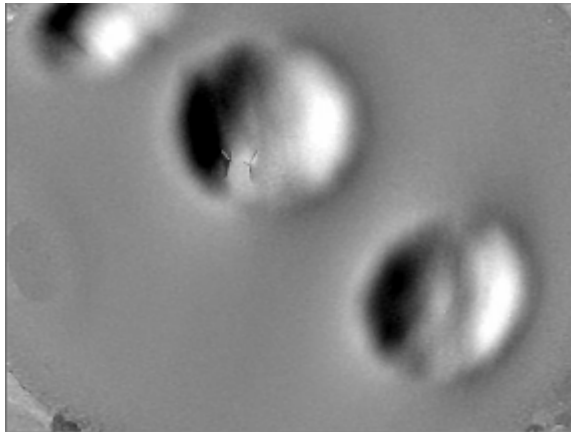
50°



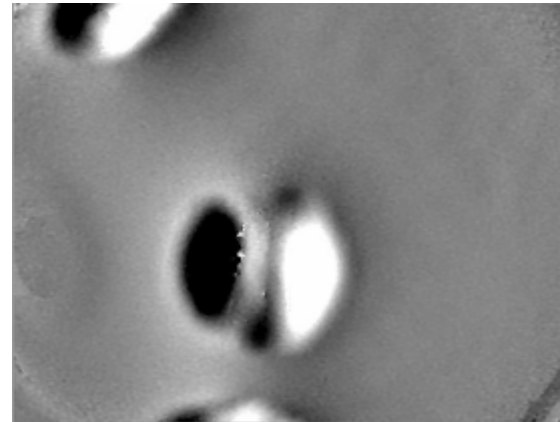
130°



230°



270°

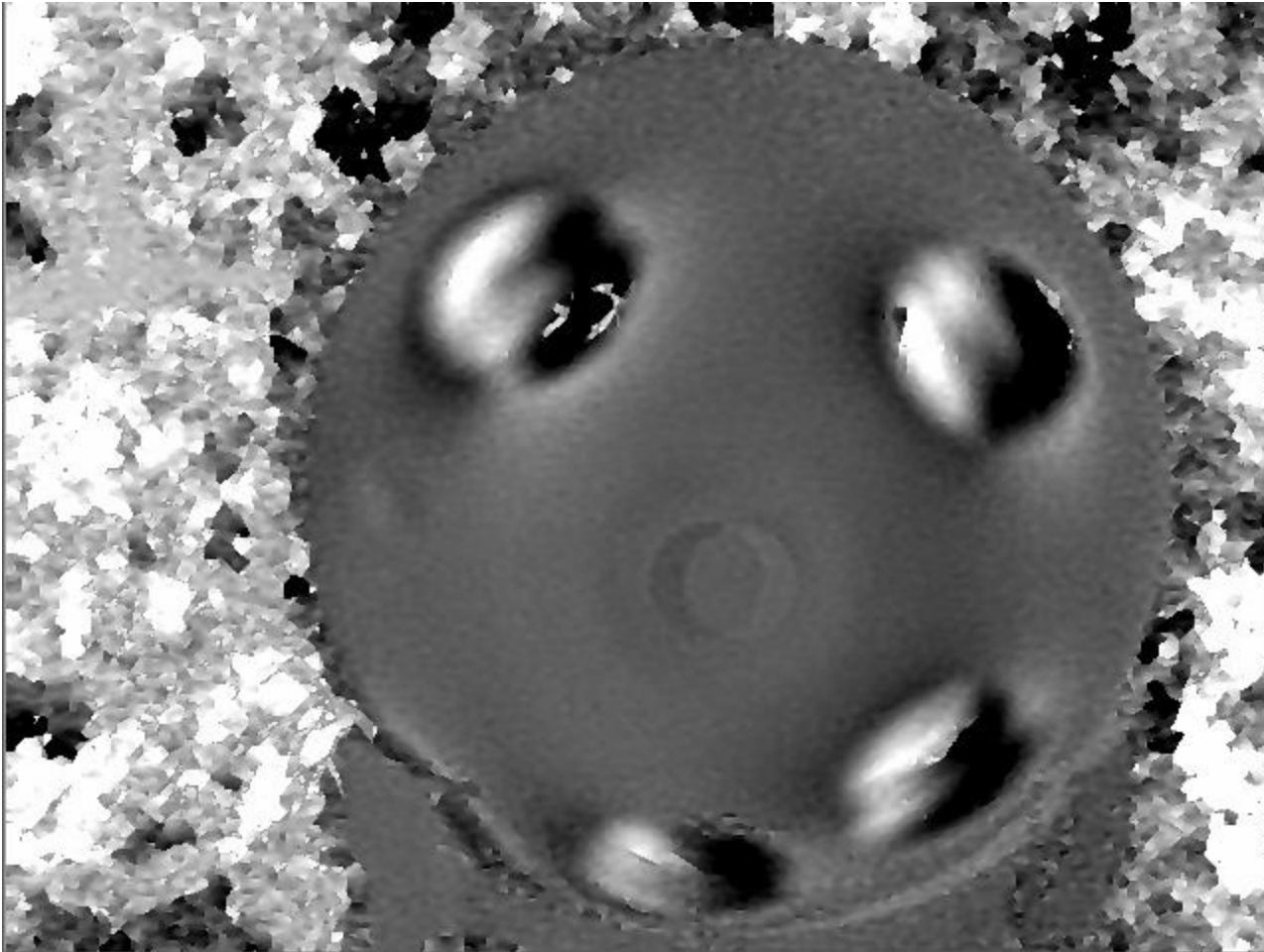


320°



# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 066



# Shearography COPV Test Data

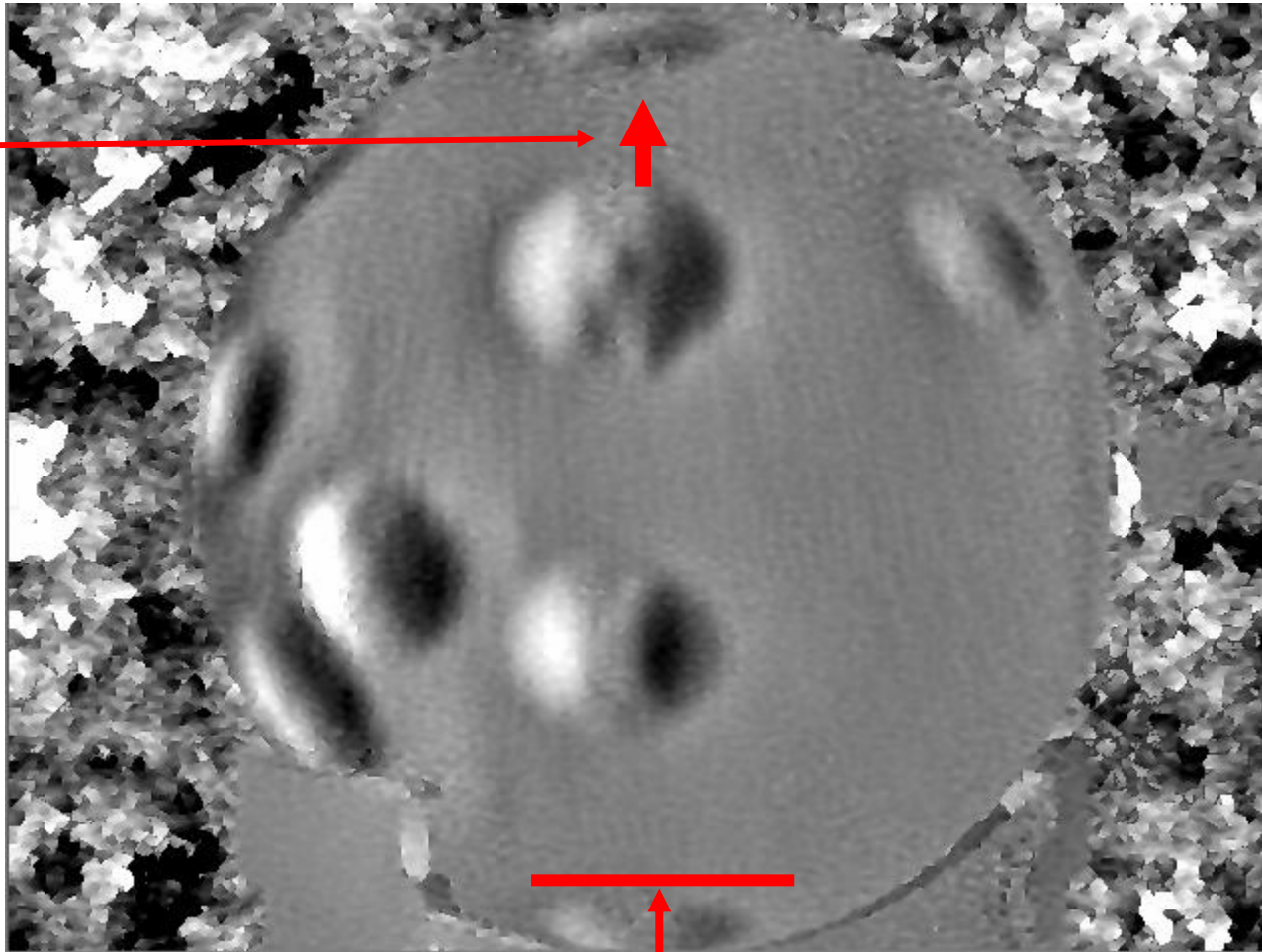
10.25 Inch Graphite Sphere  
s/n 074



# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 074

Direction of  
Rotation



0°

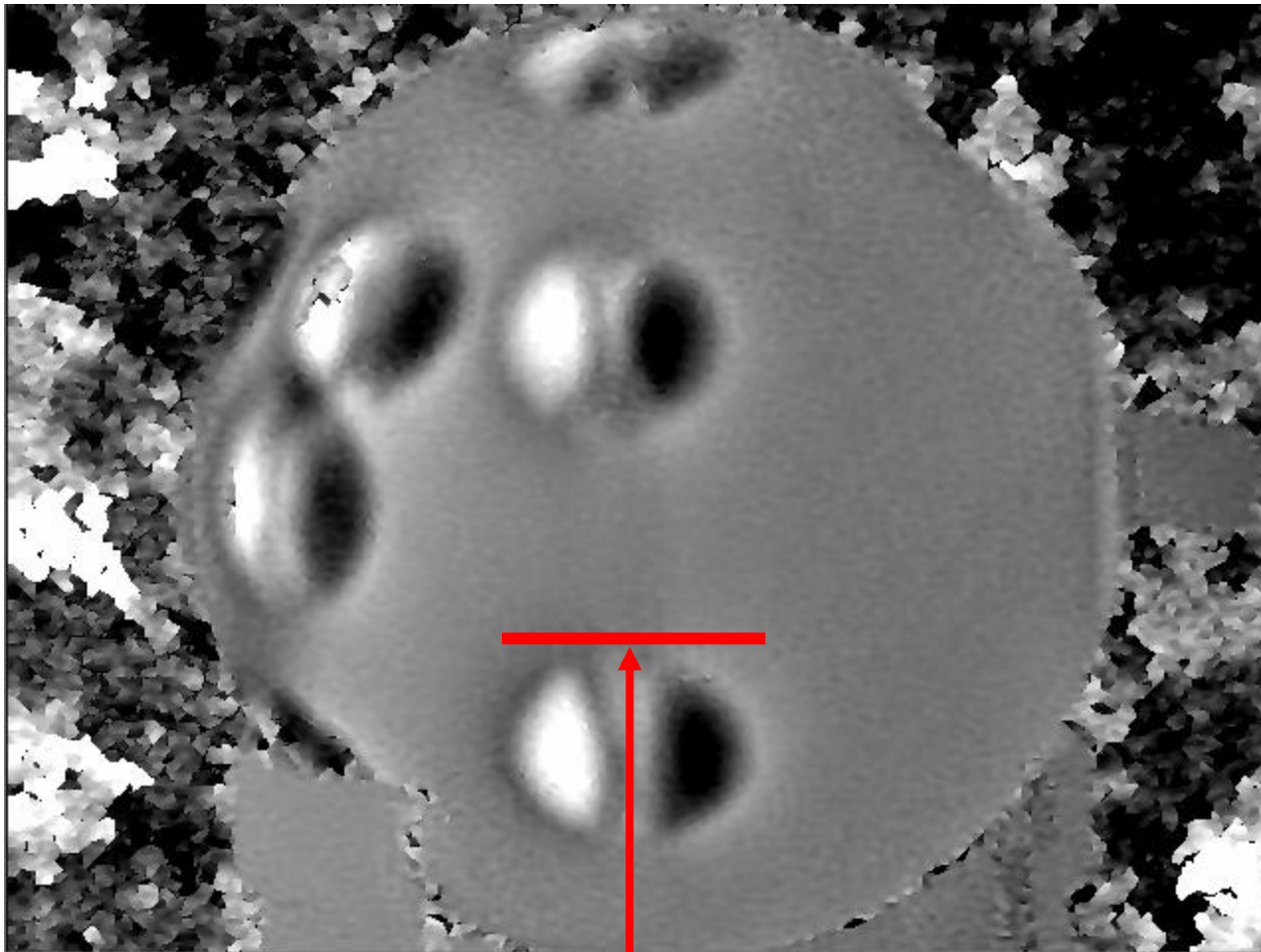


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Aerospace Inspection Systems

[www.LaserNDT.com](http://www.LaserNDT.com)

# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 074



0°

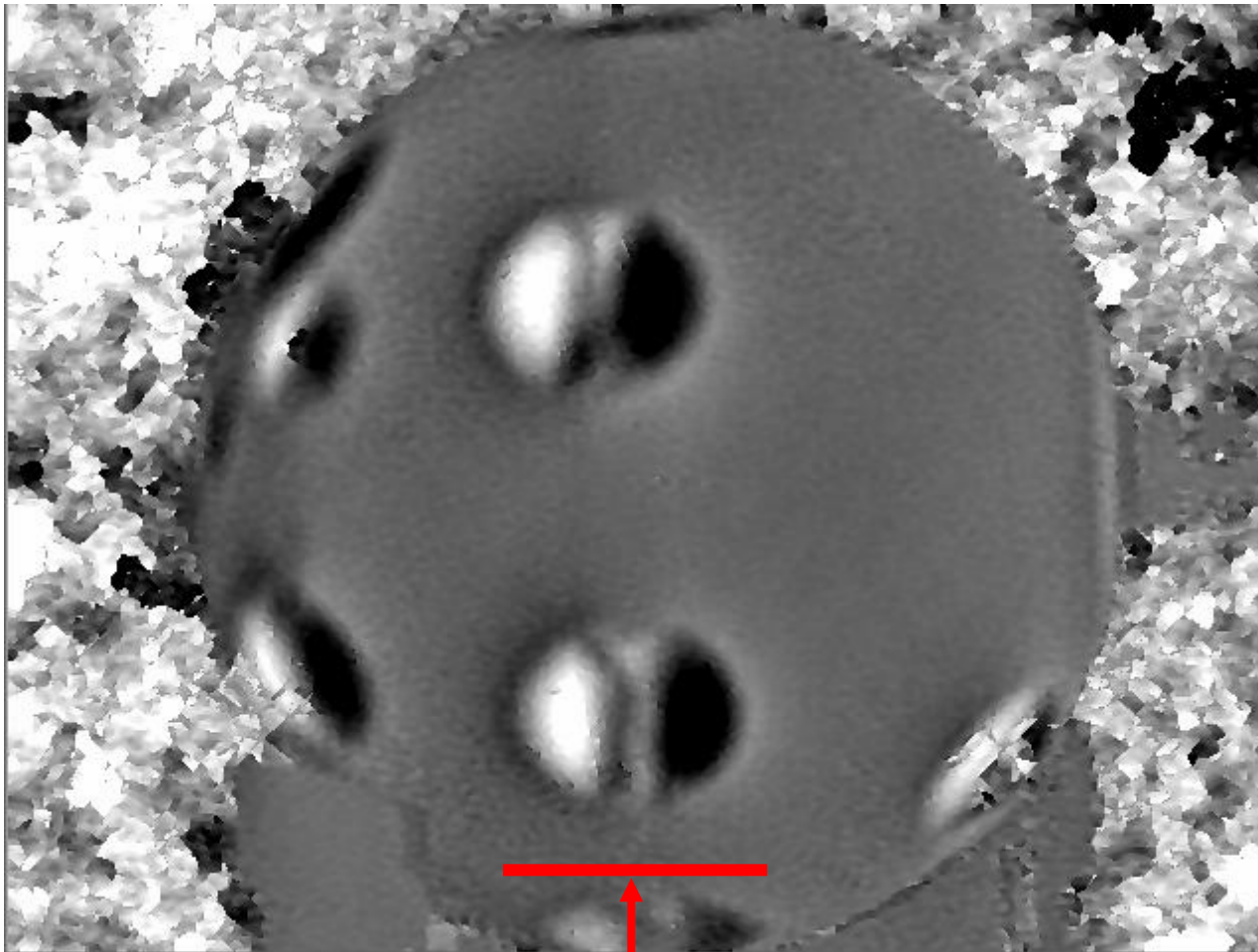


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Aerospace Inspection Systems

[www.LaserNDT.com](http://www.LaserNDT.com)

# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 074



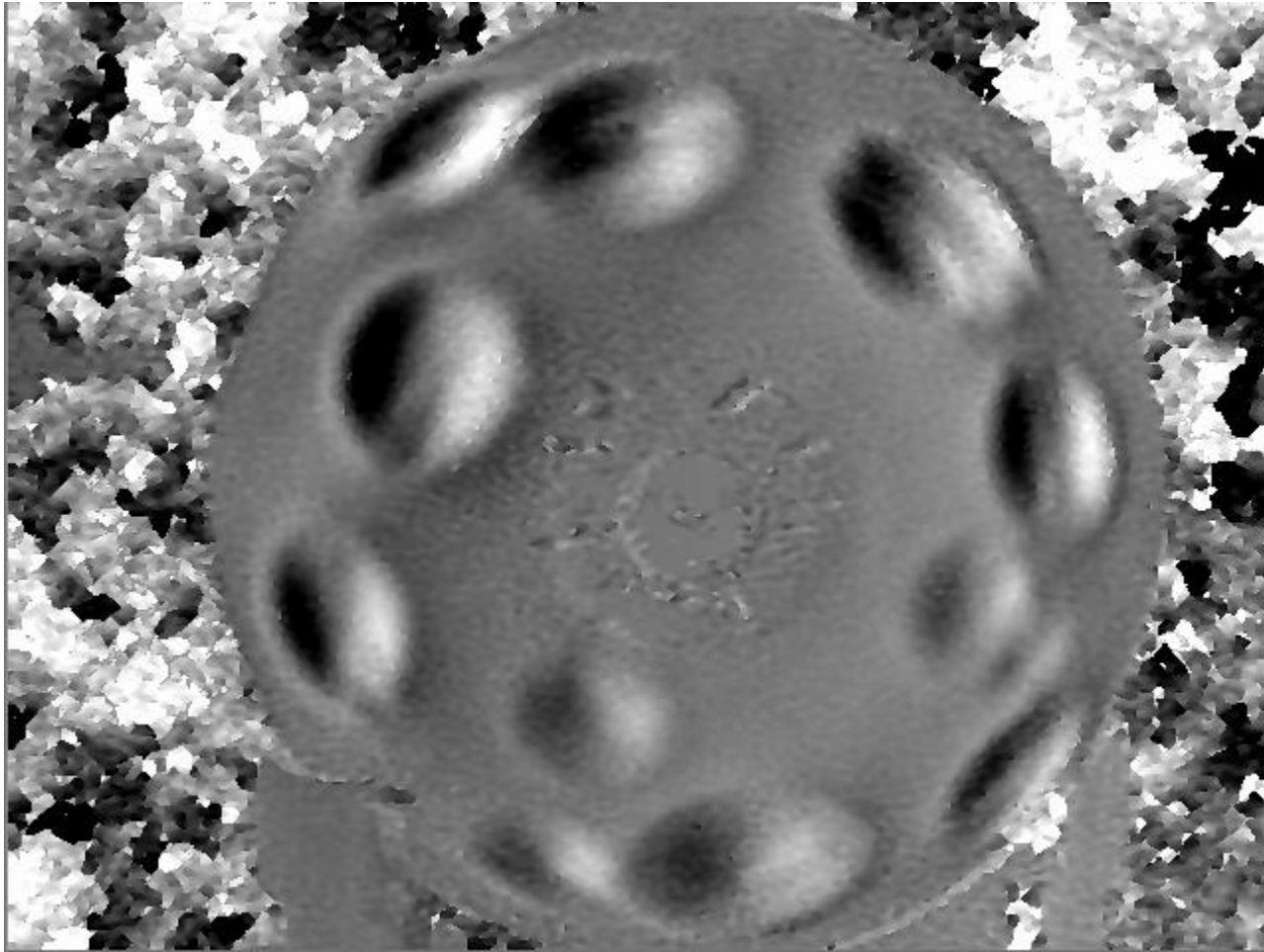
180°



# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 074

Blind Flange End View

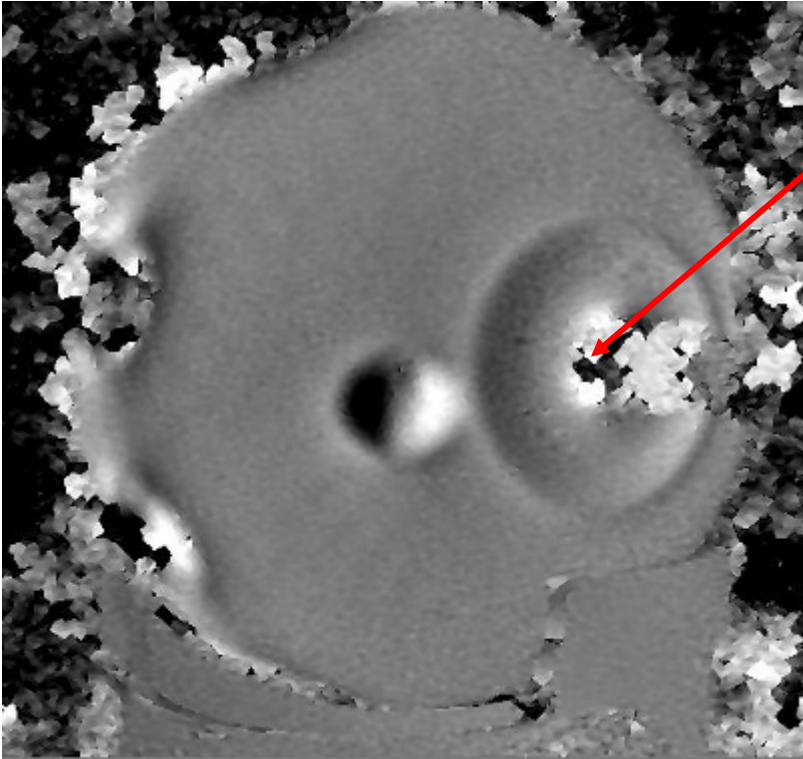




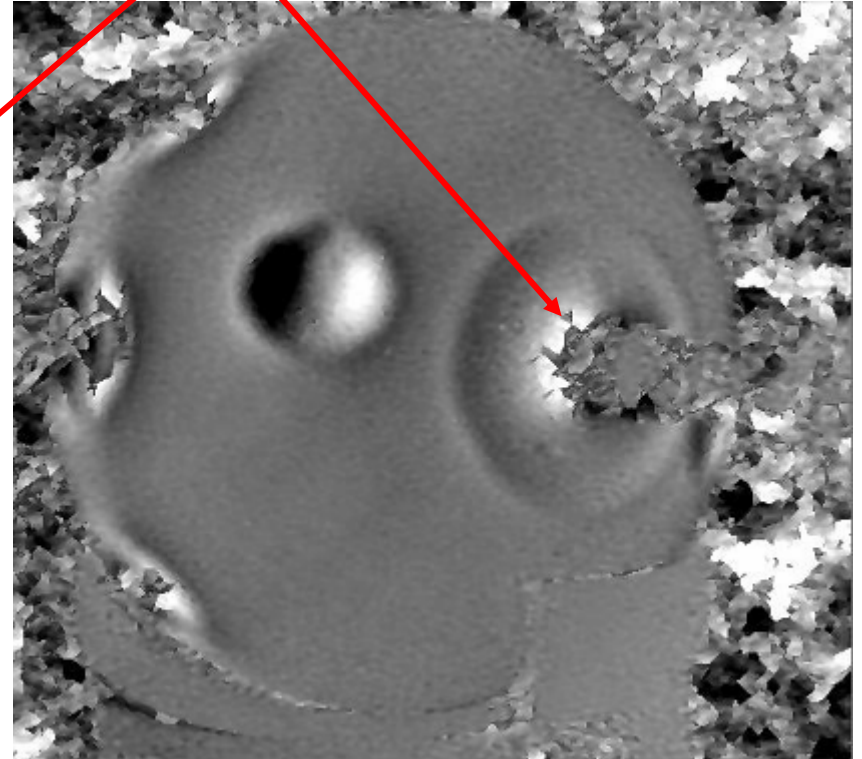
# Shearography COPV Test Data

10.25 Inch Graphite Sphere s/n 074

Gas Pressurization Flange End



255°



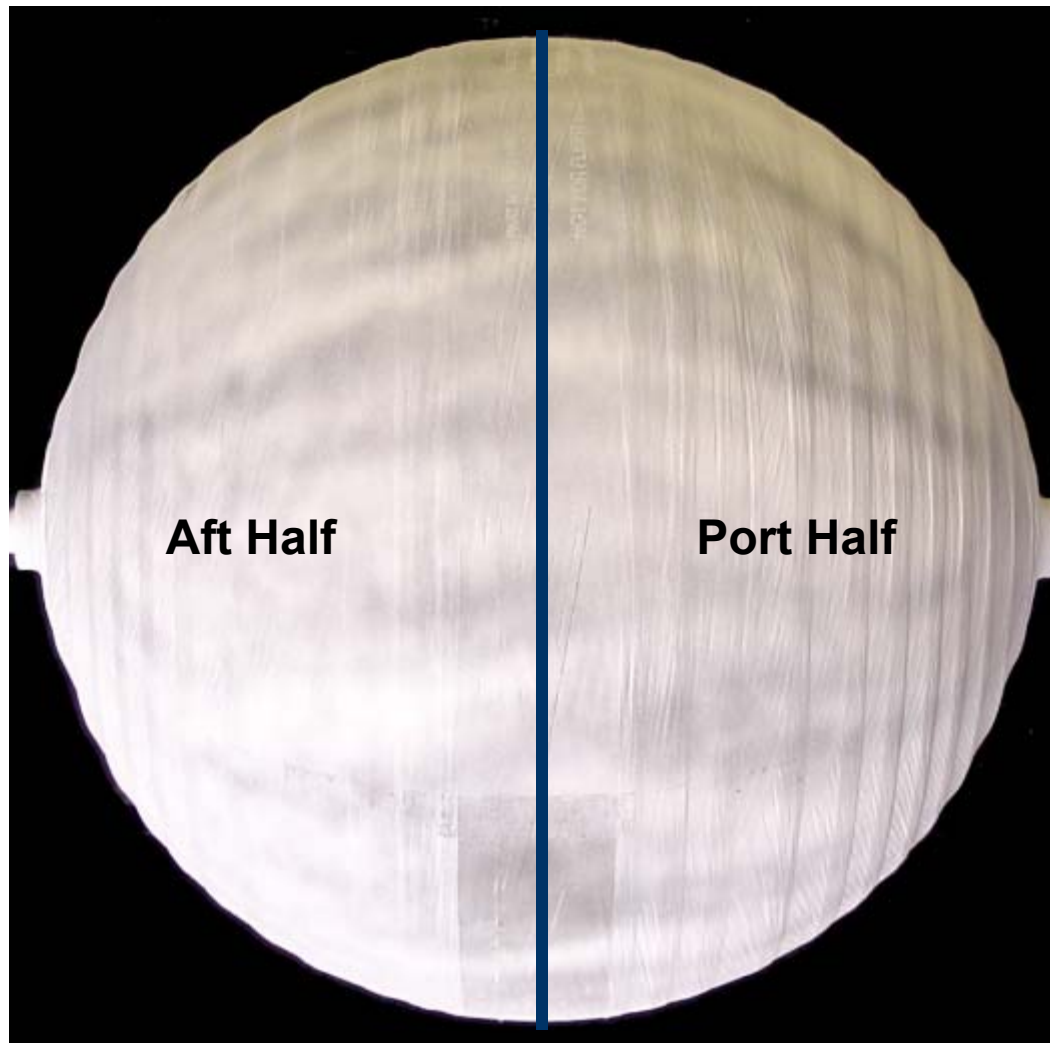
75°

# **Shearography COPV Test Data**

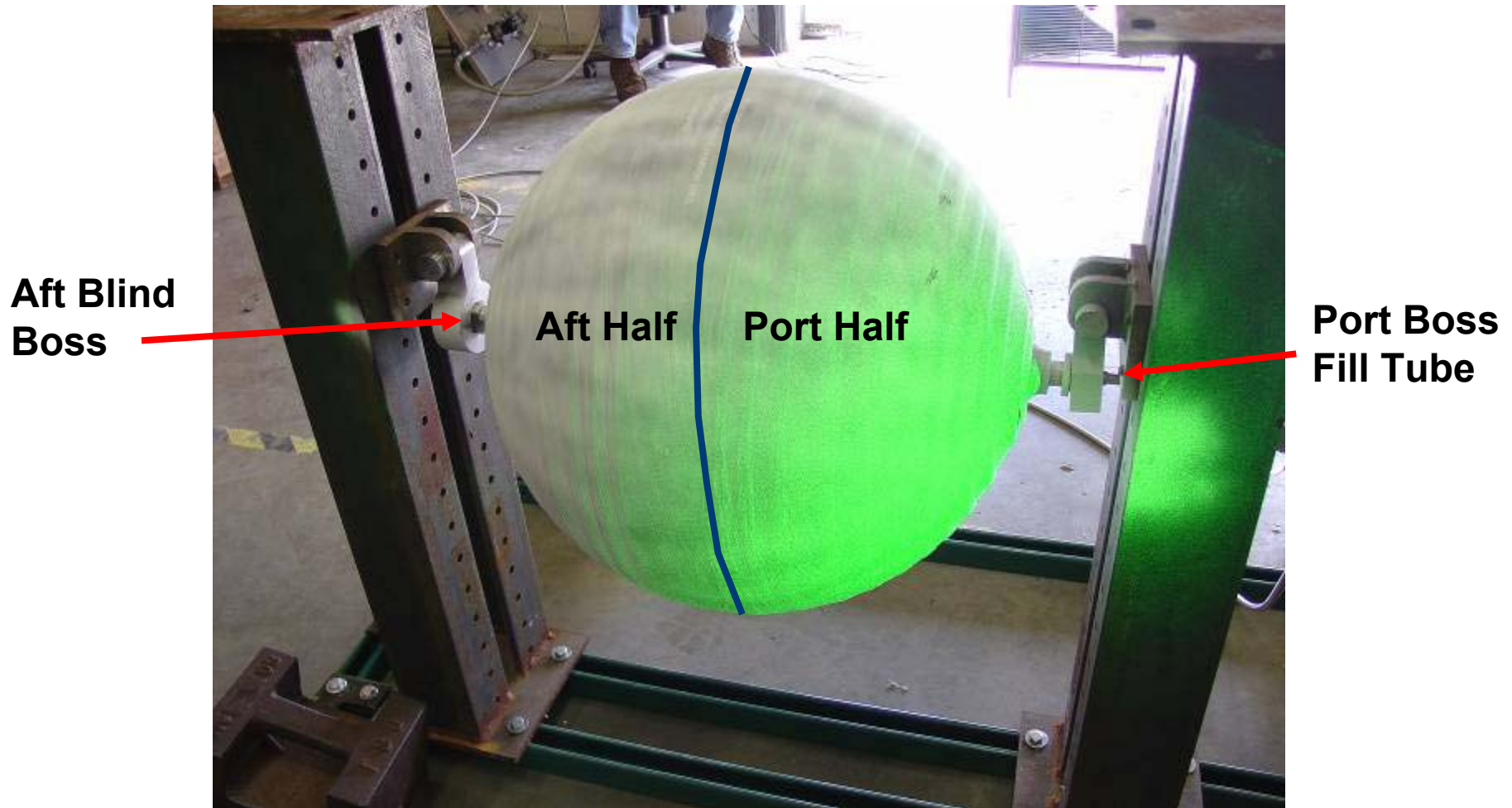
## **18 Inch Graphite Sphere**



# Shearography Scan Plan 6 x 22 Inch Graphite Cylinder

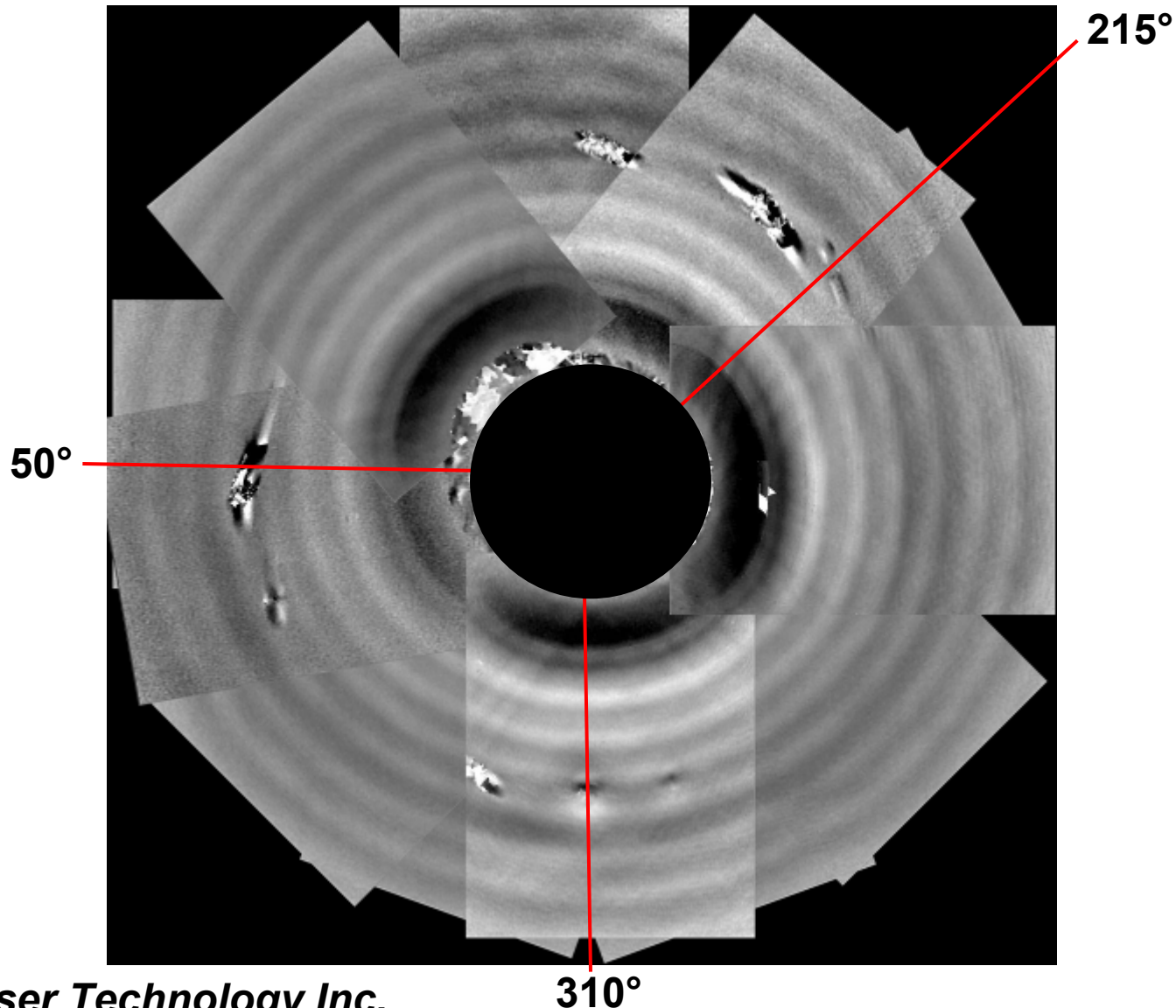


# Shearography Test Set-Up for 18 Inch Graphite Sphere COPV



# Shearography COPV Test Data

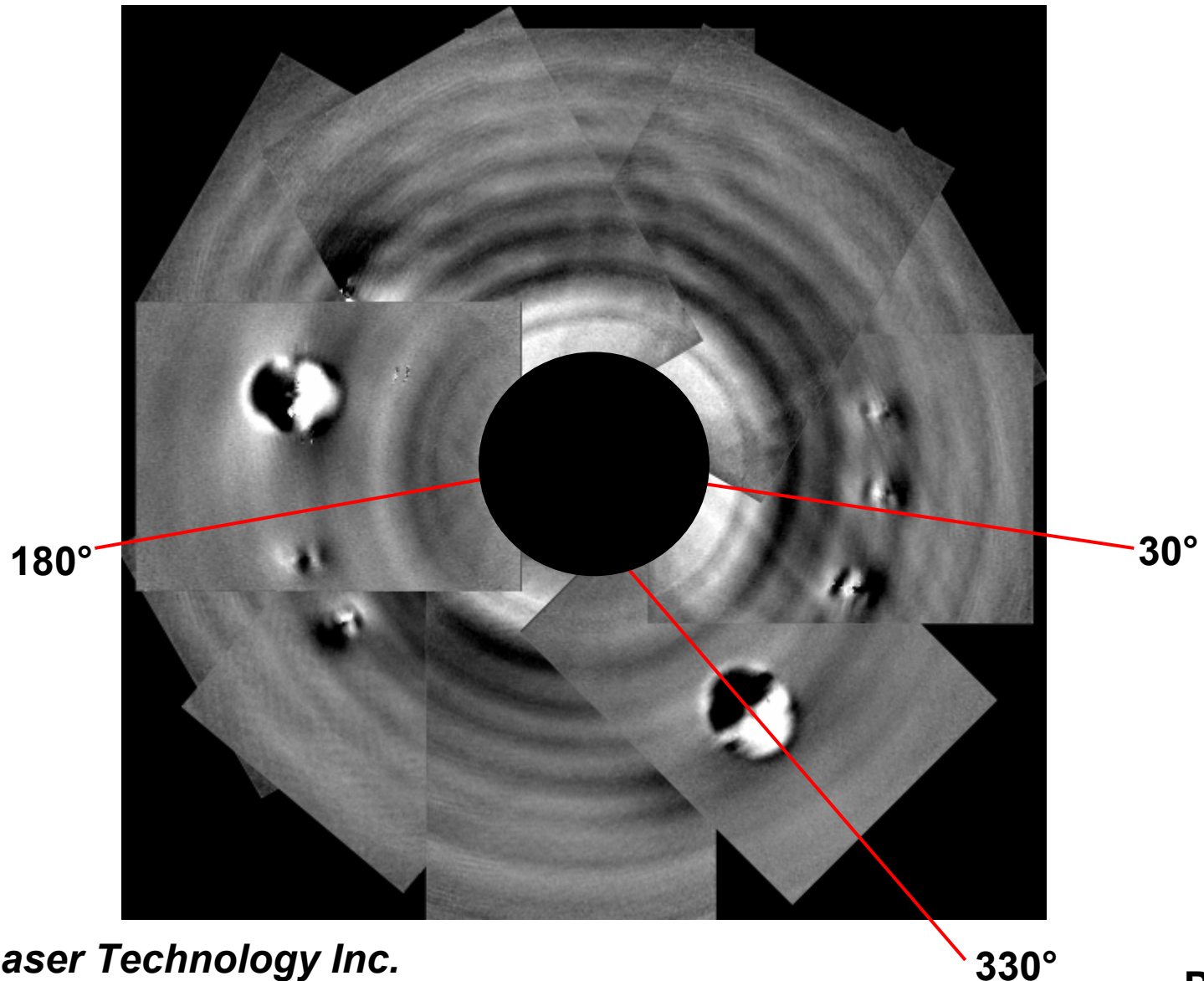
## 18 Inch Graphite Sphere s/n 010 - Port Half





# Shearography COPV Test Data

## 18 Inch Graphite Sphere s/n 010 - Aft Half





## **For More Information, Please Contact:**

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